PHYLOGENETIC EVOLUTION OF THE NEUROENDOCRINE CONTROL OF GROWTH HORMONE: CONTRIBUTION FROM TELEOSTS

by

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ABSTRACT. - Growth hormone (GH) is involved in many physiological functions such as growth, metabolism, reproduction and immunity. In mammals, it is well established that GH release is under a dual hypothalamic control, stimulatory by somatoliberin (GHRH) and inhibitory by somatostatin (SRIH). Peripheral hormones such as the insulin-like growth factors (IGFs) and the thyroid hormones (TH) can also regulate GH release. In non-mammalian vertebrates, a great variability of hypothalamic neuropeptides involved in GH stimulation seems to occur. This review underlines the important contribution of teleost models in the phylogenetic study of GH control.

Teleost somatotrophs show a high autonomous activity of synthesis and release *in vitro* in a serum-free medium and without any secretagogues. This strong autonomous activity *in vitro* suggests that these cells are under a dominant inhibitory control *in vivo*. SRIH and IGF1 have strong inhibitory effects on the release and synthesis of GH in teleosts. Concerning the stimulatory control of GH in teleosts, a great diversity of factors involved exists. Thus, depending on species or physiological stage, thyreoliberin, gonadoliberin, corticoliberin and dopamine are able to stimulate GH release. Contrary to mammals, in teleosts, PACAP, which is encoded by the same gene as GHRH, stimulates GH release, whereas GHRH has lower or no effect. Variable actions of TH in GH control are found among teleosts as well as among other vertebrates.

In conclusion, the inhibitory control exerted by SRIH and IGF1, which shows a strong molecular and functional conservation, could represent the basic neuroendocrine control of GH, established early during evolution, at least in a common ancestor of the actinopterygians and the sarcopterygians. In contrast, a great variability is seen among the hypothalamic neuropeptides involved in the stimulatory control of GH release. PACAP may represent the ancestral GH-releasing factor, whereas GHRH would have acquired a major role during tetrapod and especially mammalian evolution.

RÉSUMÉ. - Évolution phylogénétique du contrôle neuroendocrinien de l'hormone de croissance : apport des modèles téléostéens.

L'hormone de croissance (GH) est impliquée dans de nombreuses fonctions physiologiques, telles que la croissance, le métabolisme, la reproduction et l'immunité. Chez les mammifères, il est bien établi que la libération de GH est sous un double contrôle hypothalamique, stimulateur par la somatolibérine (GHRH) et inhibiteur par la somatostatine (SRIH). Des hormones périphériques comme les facteurs de croissance de type insulinique (IGFs) et les hormones thyroïdiennes (HT) peuvent également agir sur la libération de GH. Chez les vertébrés non-mammaliens, il semble exister une grande diversité quant aux neuropeptides hypothalamiques impliqués dans la stimulation de GH. Cette revue souligne l'importante contribution des modèles téléostéens dans l'étude phylogénétique du contrôle de GH.

Les cellules somatotropes de téléostéens possèdent une forte activité autonome de synthèse et de libération *in vitro* en milieu sans sérum et en absence de tout secrétagogue. Cette importante activité autonome *in vitro* suggère que ces cellules sont soumises *in vivo* à un contrôle inhibiteur dominant. SRIH et IGF1 possèdent des effets inhibiteurs puissants sur la libération et la synthèse de GH chez tous les téléostéens. En ce qui concerne le contrôle stimulateur de GH chez les téléostéens, une grande diversité de facteurs pouvant intervenir existe. Ainsi, suivant l'espèce ou le stade physiologique, la thyréolibérine, la gonadolibérine, la corticolibérine et la dopamine sont capables de stimuler la libération de GH. À l'inverse de chez les mammifères, chez les téléostéens, PACAP, qui est codé par le même gène que GHRH, stimule la libération de GH, alors que GHRH n'a pas ou moins d'effet. Des rôles variables des HT dans le contrôle de GH sont trouvés au sein des téléostéens comme des autres vertébrés.

En conclusion, le contrôle inhibiteur exercé par SRIH et IGF1, qui montre une forte conservation moléculaire et fonctionnelle, peut représenter le contrôle neuroendocrine de base de la GH, mis en place tôt au cours de l'évolution des vertébrés, au moins chez un ancêtre commun aux actinoptérygiens et sarcoptérygiens. Au contraire, il existe une forte variabilité des neuropeptides hypothalamiques impliqués dans le contrôle stimulateur de la libération de GH. PACAP pourrait avoir joué un rôle ancestral de facteur de libération de GH, tandis que GHRH n'aurait acquis un rôle majeur qu'au cours de l'évolution des tétrapodes et en particulier chez les mammifères.

Key words. - Teleosts - Growth hormone - Evolution - Regulation - SRIH - PACAP - GHRH - Ghrelin - TRH - GnRH - Dopamine - IGF - Thyroid hormone.

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Growth hormone (GH) is a pituitary hormone, which shares similar structure, function and gene organization with prolactin and somatolactin (Ono *et al.*, 1990). GH has been found in all taxonomic groups of the jawed vertebrates (gnathostomes) and, recently, also identified in the sea lamprey, an extant representative of a group of the most ancient vertebrates (jawless vertebrates) (Kawauchi *et al.*, 2002). In this study, GH appears to be the only member of the GH/prolactin/somatolactin family in this group, suggesting that GH is the ancestral hormone in the molecular evolution of this family.

GH exerts pleiotropic functions in teleosts as in other vertebrates. This hormone is better known for its essential role in the regulation of body growth and development (Björnsson, 1997; Mommsen, 2001), but it can also influence osmoregulation (Sakamoto *et al.*, 1993; McCormick, 2002; Evans, 2002), reproduction (Le Bail, 1988; Le Gac *et al.*, 1993) and immunity (Harris and Bird, 2000). GH can exert its growth-promoting actions at different levels. Affecting the central nervous system, the hormone may alter aggression (Jonsson *et al.*, 1998), physical activity patterns (Jonsson *et al.*, 2003) or appetite (Lin *et al.*, 2000). GH can influence muscle protein synthesis (Higgs *et al.*, 1975; Inui and Ishioka, 1985) directly through muscle GH receptors (Yao *et al.*, 1991) or local insulin-like growth factor 1 (IGF1) production (Perrot *et al.*, 1999), while, alternatively, it could act indirectly through hepatic production of IGF1 which in turn alters muscle protein metabolism systemically (Negatu and Meier, 1995; Degger *et al.*, 2000) via action on its receptor (Parrizas *et al.*, 1995). Furthermore, GH can control the 'supply side' by increasing intestinal growth (Sun and Farmanfarmaian, 1992) and transport phenomena (Collie and Stevens, 1985; Reshkin *et al.*, 1989; Farmanfarmaian and Sun, 1999). Finally, indirect metabolic controls should not be ignored (Company *et al.*, 2001), through effects on glucose utilization (McKeown *et al.*, 1975; Leung *et al.*, 1991), use of fat (lipolysis) for energy production (Leatherland and Nuti, 1981; Sheridan, 1994; O'Connor *et al.*, 1993) and protein synthesis (Inui and Ishioka, 1985; Foster *et al.*, 1991; Degger *et al.*, 2000).

In mammals, the regulation of GH release is primarily mediated by the dual actions of two hypothalamic hormones: growth hormone-releasing hormone (GHRH) stimulates, while somatostatin (SRIH) inhibits GH release (Bluet-Pajot *et al.*, 1998). In addition, insulin-like growth factor 1 (IGF1) secreted by the liver under GH control exerts a negative feedback on GH production (Berelowitz *et al.*, 1981).

In non-mammalian vertebrates, the situation is different. In birds, thyroliberin (TRH) is more potent than GHRH in the stimulation of GH release (Harvey, 1990), whereas in turtles, corticoliberin (CRH) is a GH-releasing factor as potent as TRH and GHRH (Denver and Licht, 1991). In teleosts, it is even more complex as the factors involved in GH control have been found to be almost as various as the number of species studied. This diversity may be related to the pleiotropic functions of GH and the different physiological stages studied. The variability of the factors controlling GH in teleosts may also reflect the large evolutionary and biological diversity of this group encompassing more than twenty thousand species (De Pinna, 1996). The investigation of GH control in the European eel (*Anguilla anguilla*), a representative of a primitive group of teleosts (Elopomorphs), is important as it may provide informations on the conservation and variation of regulations during teleost evolution.

Basal release and production of GH in teleosts

In teleosts, long-term studies have shown that basal release and synthesis of GH persists *in vitro* in the absence of secretagogues or serum, using either organ-cultured pituitaries (European eel, *Anguilla anguilla*: Baker and Ingleton, 1975; Japanese eel, *Anguilla japonica*: Suzuki *et al.*, 1990) or primary cultures of isolated pituitary cells (European eel: Rousseau *et al.*, 1998, 1999; rainbow trout, *Oncorhynchus mykiss*: Yada *et al.*, 1991; turbot, *Psetta maxima*: Rousseau *et al.*, 2001). Moreover, the autonomous basal activity of somatotrophs in teleosts is remarkably strong, and could be only weakly stimulated by GH-releasing factors, suggesting that these cells are under a dominant inhibitory control *in vivo*. An extreme situation is observed in turbot in which a lack of stimulatory effects of factors such as forskolin (activator of adenylate cyclase) or phorbol ester (activator of protein kinase C) is reported, indicating that spontaneous basal GH release may already represent the maximal secretory capacity of somatotrophs (Rousseau *et al.*, 2001). In this species, stimulatory effectors of GH release could be revealed only in the presence of somatostatin (Rousseau *et al.*, 2001), demonstrating that the major control in teleosts is inhibitory. This strong spontaneous basal activity of somatotrophs may be related to the fact that in contrast to mammals and birds, growth continues throughout adult life in fish (Johnston, 1999).

Central inhibitory control of growth hormone release and synthesis. Somatostatin, a major conserved inhibitor of GH release in vertebrates

Somatostatin (SRIH) was originally isolated from sheep hypothalamus and identified as a tetradecapeptide that inhibited the release of GH (Brazeau *et al.*, 1973). In mammals, SRIH exists as two biologically active forms, SRIH-14 and its NH2-terminal extension of 14 amino acids, SRIH-28; both these forms are derived from differential processing of a common precursor preprosomatostatin I (PPSS-I) (Patel, 1999). In contrast, in teleosts two precursors for SRIH, PPSS I and PPSS II, encoded by two separate genes, have been reported (Conlon *et al.*, 1997; Lin and Peter, 2001), and recently, a third precursor, PPSS III, with [Pro2] SRIH-14 at its C terminus, has been isolated from goldfish brain (Lin *et al.*, 1999). Posttranslational processing of PPSS I gives rise to SRIH-14, whereas PPSS II generates NH2-terminally extended forms of SRIH such as anglerfish-28 (a homologue of mammalian SRIH-28) and catfish-22. A total conservation of the primary structure of SRIH-14 has been found among mammals, birds, amphibians, reptiles, teleosts, an elasmobranch and a cyclostom (Conlon *et al.*, 1997).

In the European eel, SRIH-14 has been isolated and sequenced from the pancreas (Conlon *et al.*, 1988). A 25-amino-acid-residue peptide derived from PPSS II is also present (Conlon *et al.*, 1988). SRIH-14 immunoreactive perikarya were observed in the brain, and fibers shown in the pituitary on the basal lamina along GH cells (Olivereau *et al.*, 1984). SRIH-14 dose-dependently inhibited GH release from pituitary cells *in vitro*, for up to 12 days without desensitization and with a maximal effect of 95% inhibition (Rousseau *et al.*, 1998). Mammalian SRIH-28 was equipotent with SRIH-14 in reducing GH release. Measurement of GH cell content indicated that SRIH was also able to inhibit GH synthesis, a result that was confirmed by assay of eel GH mRNA. These results underline the possible existence of a chronic physiological inhibitory control *in vivo* of GH release and synthesis by somatostatin in the eel. This is consistent with the strong and sustained spontaneous activity of eel GH cells observed when isolated from all hypothalamic outputs and in absence of secretagogues *in vitro* (Rousseau *et al.*, 1998).

Other *in vitro* studies also demonstrated SRIH inhibition of GH release in all the teleost species studied so far (goldfish, *Carassius auratus*: Wong *et al.*, 1993a; tilapia, *Oreochromis mossambicus*: Fryer *et al.*, 1979; Melamed *et al.*, 1995, 1996; rainbow trout, *Oncorhynchus mykiss*: Luo *et al.*, 1990; Le Bail *et al.*, 1991; Luo and McKeown, 1991a; Perez-Sanchez *et al.*, 1992; Japanese eel: Suzuki *et al.*, 1990; turbot: Rousseau *et al.*, 2001). In the goldfish, SRIH was also shown to be inhibitory *in vivo* when injected intraperitoneally (Cook and Peter, 1984). However, in contrast to its action in the eel, SRIH-14 does not suppress expression of GH gene in rainbow trout (Yada and Hirano, 1992) or tilapia (Melamed *et al.*, 1996). Whereas in goldfish mammalian SRIH-28 was equipotent with SRIH-14 in reducing basal GH secretion, catfish SRIH-22 and salmon SRIH-25 were not effective in inhibiting GH release *in vitro* (Marchant *et al.*, 1987; Marchant and Peter, 1989). Nevertheless, catfish SRIH-22 was shown to inhibit GH secretion from rat anterior pituitary cells (Oyama *et al.*, 1980) and in coho salmon, *Oncorhyn-*

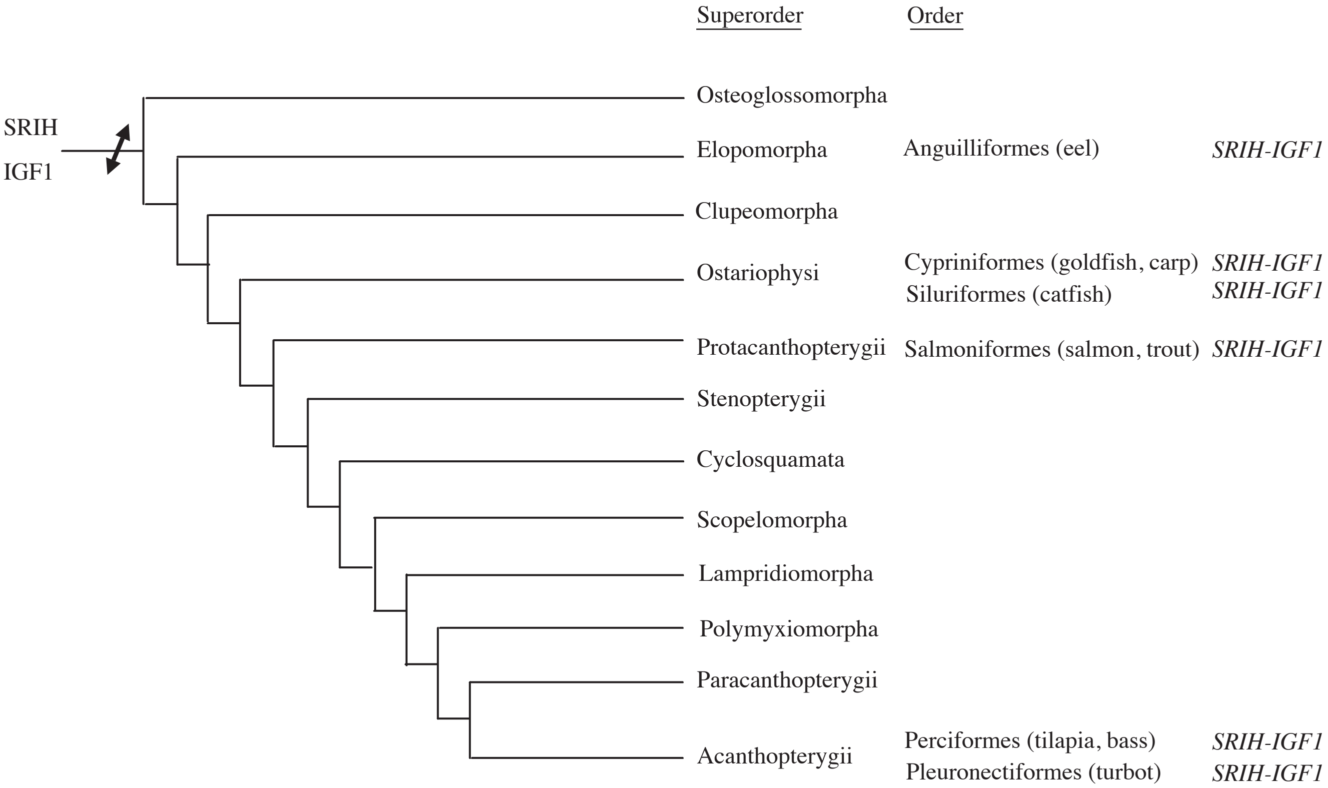

Figure 1. - Conservation of the central and peripheral inhibitory controls of growth hormone (GH) release in teleosts. In all teleost species investigated, GH release is inhibited centrally by the brain neuropeptide somatostatin (SRIH) and peripherally by the hepatic insulin like growth factor 1 (IGF1), the secretion of which is stimulated by GH.

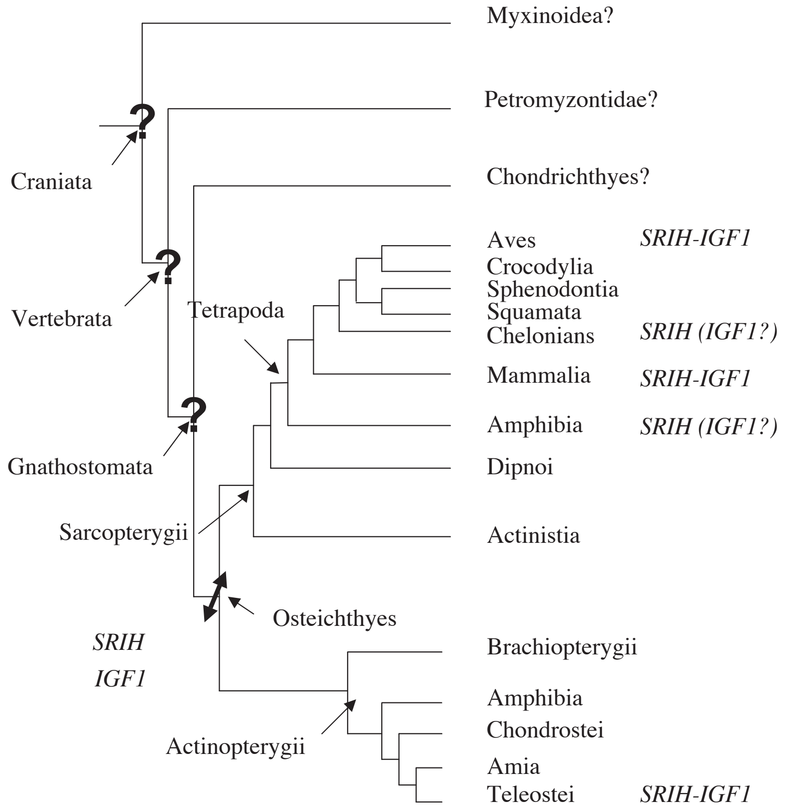

Figure 2. - Conservation of the inhibitory control of GH release in vertebrates. The conserved inhibitory control exerted by SRIH and IGF1 may represent the basic neuroendocrine control of GH, established early during vertebrate evolution, at least in an ancient osteichthyan species, common ancestor of the actinopterygian and the sarcopterygian lineages. Further investigations in representatives of earlier groups, such as chondrichthyes, lampreys, and myxins would allow to trace a possible more ancient origin of these inhibitory controls.

chus kisutch, SRIH-14, mammalian SRIH-28 and SRIH-25 significantly decreased plasma GH concentrations (Diez *et al*., 1992). The recent cloning and localisation of 8 somatostatin receptors (two type-one, one type-two, two type-three and three type-five) in the goldfish demonstrated the predominant expression of both sst2 and sst5 in the pituitary which is consistent with the findings in mammals that sst2 and sst5 are predominantly expressed in pituitary somatotrophs and involved in the direct regulation of GH secretion (Lin and Peter, 2003). Previous data using receptor subtype-selective somatostatin agonists in the eel suggested the existence of SRIH receptor(s) related to mammalian sst2/sst3/sst5 class rather than to sst1/sst4 class on somatotrophs (Rousseau *et al*., 1998).

These data indicate that SRIH is an inhibitor of basal GH release in all teleosts studied so far. In contrast, in other vertebrates such as birds (Hall and Chadwick, 1976; Harvey *et al*., 1978; Leung and Taylor, 1983; Perez *et al*., 1987), turtles (Hall and Chadwick, 1984) and amphibians (Hall and Chadwick, 1984; Jeandel *et al*., 1998), its inhibitory action may require the presence of stimulators of GH release and is subject to rapid desensitization.

In summary, these data indicate that somatostatin is a potent inhibitor of GH release in teleosts (Fig. 1) as in other vertebrates (Fig. 2) and may represent the major ancestral control of GH during evolution.

Central stimulatory control of growth hormone release and synthesis

PACAP, instead of GHRH, may be the major GH-releasing factor in teleosts

In mammals, GHRH represents the major stimulator of GH release. Nevertheless, its sequence is not well conserved during evolution, with fish GHRHs sharing only 35-40% identity with human GHRH and 58-91% between them (Chan *et al*., 1998). Pituitary adenylate cyclase-activating polypeptide (PACAP) is a 38-amino acid C-terminally-amidated polypeptide that was first isolated from ovine hypothalamus for its ability to stimulate adenylate cyclase activity in rat pituitary cells (Miyata *et al*., 1989). Processing of PACAP can generate a 27-amino acid amidated peptide (PACAP27), which possesses the same biological activity as PACAP38 (Miyata *et al*., 1990). PACAP is a member of the VIP/secretin/glucagon/GHRH/GIP superfamily (Vaudry *et al*., 2000). In contrast to GHRH, its sequence is highly conserved during evolution from protochordates to mammals (Montero *et al*., 2000). Interestingly, PACAP and GHRH have been shown to be encoded by the same gene in non-mammalian species including an urochordate (McRory and Sherwood, 1997a), teleosts (Parker *et al*., 1993; McRory *et al*., 1995), amphibians (Alexandre *et al*., 2000; Hu *et al*., 2000) and birds (McRory *et al*., 1997), while they are encoded by two distinct homologous genes in mammals (Ogi *et al*., 1990, Ohkubo *et al.*, 1992; Okazaki *et al.*, 1995). Studies conducted in mammals have shown that PACAP and its receptors are widely distributed in the central nervous system and in peripheral tissues (Vaudry *et al.*, 2000).

In the eel, PACAP was characterized in the brain by HPLC and RIA studies and a major form co-eluted with mammalian PACAP38 (Montero *et al.*, 1998). Immunocytochemical studies in the eel indicated a strong innervation by PACAP-immunoreactive fibers of the pars distalis of the pituitary, where somatotrophs are located (Montero *et al.*, 1998). In contrast, only rare GHRH immunoreactive fibers were detected in this region. Both PACAP 38 and 27 were able to stimulate GH release by eel pituitary cells with the same maximal effect (about 300% over basal release) (Montero *et al.*, 1998; Rousseau *et al.*, 1999). PACAP GH-releasing effect was maximal at 24h of incubation and then submitted to desensitization. Dose-response studies indicated that PACAP38 was approximately 12 times more potent than PACAP27. No effect on GH release was observed *in vitro* using either human GHRH or goldfish GHRHs (carp-like and catfish-like) (Leung *et al.*, 1999) at any doses and any time of incubation (Rousseau *et al.*, 2001).

PACAP was also shown to be effective in stimulating GH release in all teleost species studied (salmon: Parker *et al.*, 1997; goldfish: Wong *et al.*, 1998a; turbot: Rousseau *et al.*, 2001). Treatment with human GHRH was reported to stimulate GH release in rainbow trout *in vitro* (Le Bail *et al.*, 1991) and goldfish *in vivo* (Peter *et al.*, 1984). In cyprinids, a GHRH-like peptide has been isolated from the carp hypothalamus and found to stimulate GH release, in goldfish *in vitro* from pituitary fragments and *in vivo* (Vaughan *et al.*, 1992), and in rainbow trout from pituitary cells (Luo *et al.*, 1990; Luo and McKeown, 1991a). Nevertheless, in goldfish pituitary, rare GHRH-immunoreactive fibers were observed in the region of GH cells, whereas strong PACAP immunoreactivity was found in the *pars distalis* where somatotrophs are located (Rao *et al.*, 1996; Wong *et al.*, 1998a). In all species studied so far (salmon: Parker *et al.*, 1997; goldfish: Wong *et al.*, 1998a; European eel: Montero *et al.*, 1998; Rousseau *et al.*, 1999), PACAP was far more efficient than GHRH in stimulating GH release. The lack of GH-releasing effect observed in the eel was also reported in turbot (Rousseau *et al.*, 2001), while GHRH had a very limited effect in salmon (Parker *et al.*, 1997), in tilapia (Melamed *et al.*, 1995) and catfish (Lescroart *et al.*, 1996).

In the frog, PACAP and GHRH possess similar stimulatory effects on GH release *in vitro* (Martinez-Fuentes *et al.*, 1994), while in chicken (Peeters *et al.*, 1998) and mammals (Nagy *et al.*, 1993; Goth *et al.*, 1992), PACAP is a less potent GH-releasing factor than GHRH.

These data strongly suggest that PACAP, instead of GHRH, may be the major GH-releasing factor in teleosts

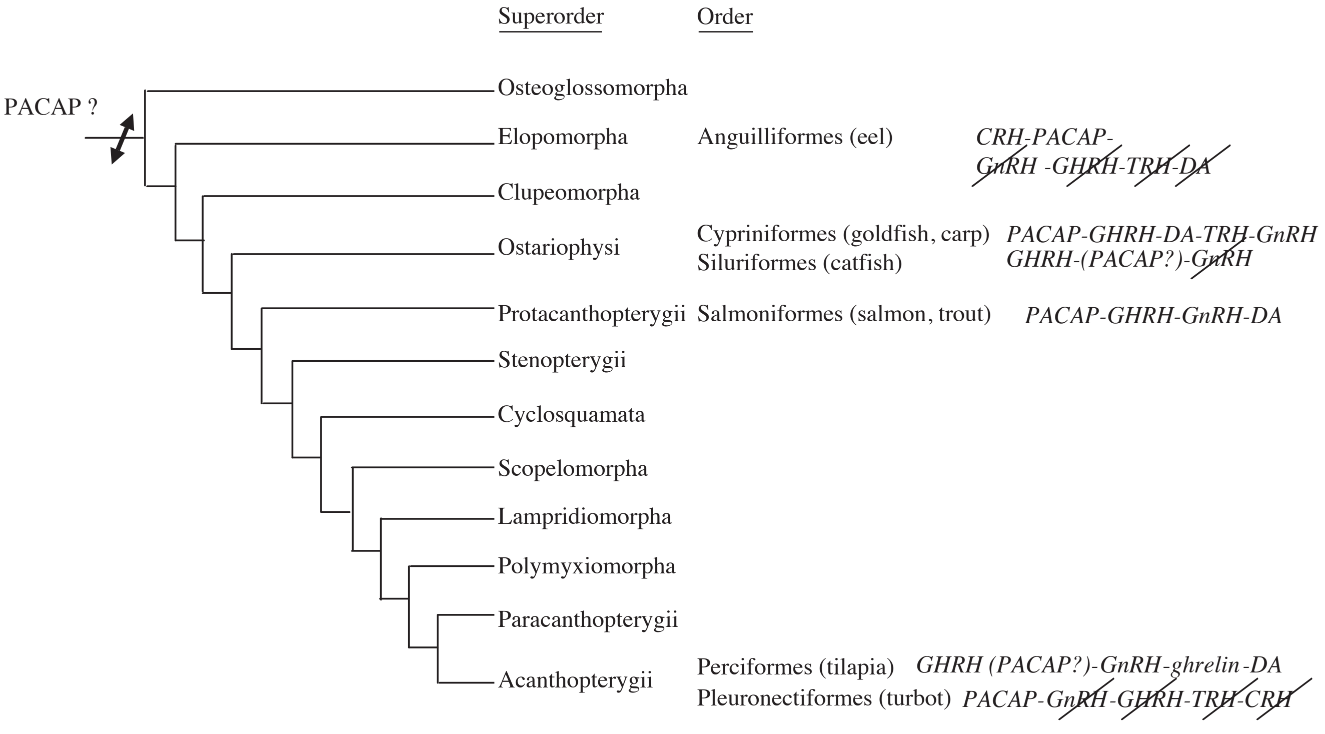

Figure 3. - Variability of the stimulatory control of GH in teleosts. A diversity of neurohormones have been shown to act as GH-releasing factors in teleosts, with variations depending on the species and physiological status. Pituitary adenylate cyclase-activating polypeptide (PACAP) may represent a common major factor. CRH: corticotropin-releasing hormone; DA: dopamine; GHRH: growth hormone-releasing hormone; GnRH: gonadotropin-releasing hormone; TRH: thyrotropin-releasing hormone.

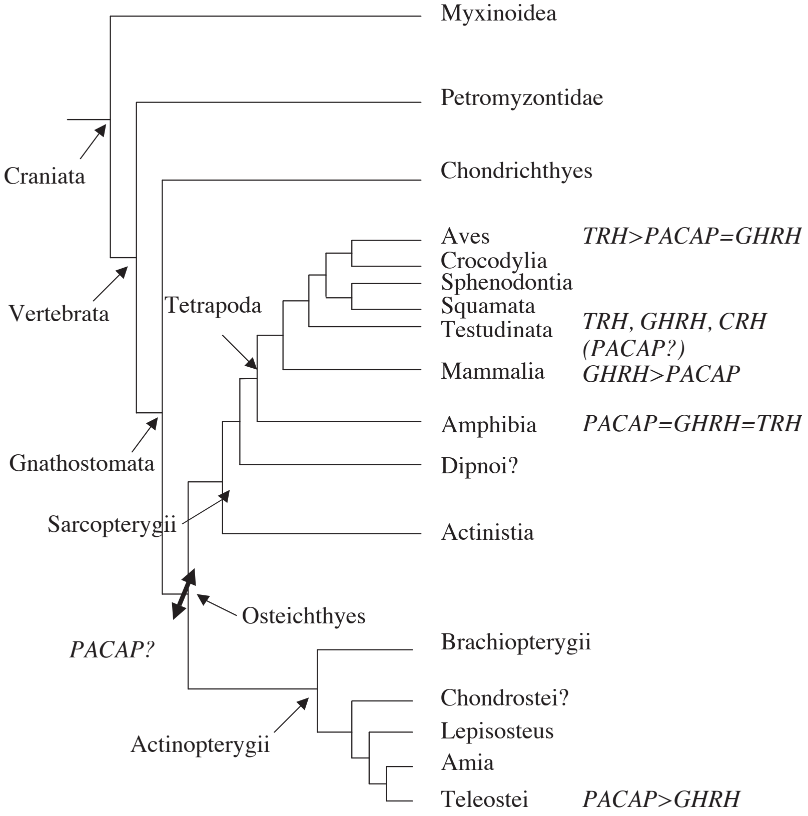

Figure 4. - Variability of the stimulatory control of GH in vertebrates. A great variability is seen among the hypothalamic neuropeptides involved in the stimulatory control of GH. PACAP may represent an ancestral GH-releasing factor, whereas growth hormone-releasing hormone (GHRH) would have acquired a major role during mammalian evolution. Further investigations in representatives of earlier groups of actinopterygians (such as chondrosteans) and of sarcopterygians (such as dipnoi) would allow to confirm the nature of the ancestral stimulatory control in osteichthyes.

(Fig. 3). GHRH may have progressively acquired its major role in the stimulatory control of GH during later tetrapod evolution (Fig. 4).

Diversity and species variations in GH-releasing factors in teleosts (Tab. I; Fig. 3)

Beside PACAP or GHRH, a variety of other neurohormones have been shown to act as GH-releasing factor in teleosts, with species-specific variations. Gonadotropin-releasing hormone (GnRH) decapeptides are the primary stimulators of gonadotropin secretion in vertebrates. The primary structures of 23 GnRHs are known at this time (Adams *et al.*, 2003). In the brain, cGnRH-II generally coexists with one or more GnRH forms in all the major vertebrates groups including mammals, birds, reptiles, amphibians and teleost fishes (Montero and Dufour, 1996; Lin *et al.*, 1998). In the goldfish, salmon GnRH (sGnRH), sea bream GnRH (sbGnRH), herring GnRH, cGnRH II and some analogs of mammalian GnRH were effective in stimulating both GH release (*in vivo*: Marchant *et al.*, 1989; *in vitro*: Chang and de Leeuw, 1990; Murthy *et al.*, 1994; Carolsfeld *et al.*, 2000) and GH mRNA (Klausen *et al.*, 2001, 2002). These results are consistent with the finding of GnRH receptors on goldfish somatotropes (Cook *et al.*, 1991). GnRHs were also reported to stimulate GH release in tilapia (Melamed *et al.*, 1995, 1998) and both GH release and mRNA levels in common carp, *Cyprinus carpio* (Li *et al.*, 2002). In contrast, in the eel, mammalian GnRH (mGnRH) and chicken GnRH II (cGnRH II), the two GnRH forms present in the hypothalamo-pituitary axis (Montero *et al.*, 1994) did not have any effect on GH release *in vitro* (Rousseau *et al.*, 1999). In the rainbow trout, the effect of GnRH on GH release is still controversial as stimulatory (Le Gac *et al.*, 1993) and no effects (Blaise *et al.*, 1995a) have been reported, even when GnRH neurons were shown to project to GH cells (Parhar and Iwata, 1994). Weil *et al.* (1999) showed that GH cells in rainbow trout required exposure to IGF1 to be responsive to GnRH, and Madigou *et al.* (2000) reported a weak expression of GnRH receptor in the proximal *pars distalis* of trout pituitary. In another salmonid, the sockeye salmon (*Oncorhynchus nerka*), GnRH analog did not induce significant increase in the levels of GH mRNAs *in vivo* (Taniyama *et al.*, 2000). In African catfish (*Clarias gariepinus*), GnRH was not able of inducing GH release (Lescroart *et al.*, 1996) and specific binding sites for GnRH cannot be found on catfish somatotropes (Bosma *et al.*, 1997). No effect of the three forms (cGnRH II, sGnRH and sbGnRH) found in recent teleosts such as percomorphs were observed on GH release from turbot pituitary cells (Rousseau *et al.*, 2001).

Thyrotropin-releasing hormone (TRH), a tripeptide initially discovered for its stimulatory effect on thyrotropin (TSH) release in mammals, was shown to be a GH secreta-

Table I. - Variability of the stimulatory control of growth hormone (GH) release in teleosts. +: stimulatory effect; 0: no effect; +/- stimulatory or inhibitory effect. CRH: corticotropin-releasing hormone; DA: dopamine; GHRH: growth hormone-releasing hormone; GnRH: gonadotropin-releasing hormone; PACAP: Pituitary adenylate cyclase-activating polypeptide; TRH: thyrotropin-releasing hormone.

GH-releasing factors	Action	Species	References
GHRH	+	rainbow trout	Luo *et al.*, 1990
	+	goldfish	Vaughan *et al.*, 1992
	+	salmon	Parker *et al.*, 1997
	+	tilapia	Melamed *et al.*, 1995
	+	African catfish	Lescroart *et al.*, 1996
	0	European eel	Montero *et al.*, 1998
	0	turbot	Rousseau *et al.*, 2001
PACAP	+	salmon	Parker *et al.*, 1997
	+	European eel	Montero *et al.*, 1998
	+	goldfish	Wong *et al.*, 1998
	+	turbot	Rousseau *et al.*, 2001
GnRH	+	goldfish	Chang *et al.*, 1990a
	+	tilapia	Melamed *et al.*, 1995
	+	carp	Li *et al.*, 2002
	+	rainbow trout	Le Gac *et al.*, 1993
	0	rainbow trout	Blaise *et al.*, 1995a
	0	African catfish	Lescroart *et al.*, 1996
	0	European eel	Rousseau *et al.*, 1999
	0	turbot	Rousseau *et al.*, 2001
TRH	+	goldfish	Trudeau *et al.*, 1992
	+	carp	Lin *et al.*, 1993
	0	tilapia	Melamed *et al.*, 1995
	0	European eel	Rousseau *et al.*, 1999
	0	turbot	Rousseau *et al.*, 2001
CRH	+	European eel	Rousseau *et al.*, 1999
	0	turbot	Rousseau *et al.*, 2001
DA	+	goldfish	Chang *et al.*, 1985
	+	tilapia	Melamed *et al.*, 1995
	+	carp	Wong *et al.*, 1998b
	+	rainbow trout	Agustsson *et al.*, 2000
	0	European eel	Vidal *et al.*, 2000
Ghrelin	+	tilapia	Kaiya *et al.*, 2003a, 2003b
Melatonin	+/-	rainbow trout	Falcon *et al.*, 2003

gogue *in vitro* in the goldfish (Trudeau *et al.*, 1992), and in the carp (Lin *et al.*, 1993; Kagabu *et al.*, 1998), but was ineffective in tilapia (Melamed *et al.*, 1995), turbot (Rousseau *et al.*, 2001), nor in eel (Rousseau *et al.*, 1999). The lack of effects of GnRH, TRH and DA in the eel may be related to teleost species differences, biological cycle and/or to the physiological stage studied. Indeed, for example, in the goldfish, GH response to GnRH and TRH has been shown to be higher in sexual mature fish and was potentiated by steroid treatment (Trudeau *et al.*, 1992). TRH has been shown to be a potent GH releasing factor in some chelonian reptiles (Denver and Licht, 1991) and birds (Harvey, 1990).

In mammals, corticotrophin-releasing hormone (CRH) is acknowledged as the primary hypothalamic factor mediating stress-induced adrenocorticotropin (ACTH) secretion from the anterior pituitary (Rivier and Plotsky, 1986). Its sequence, as well as its ACTH-releasing action, has been highly conserved throughout vertebrate evolution, from teleosts to mammals (Lovejoy and Balment, 1999). We demonstrated that CRH is able to induce GH release by eel somatotrophs in a dose-dependent manner, with a maximal effect > 400%. As for PACAP, GH-releasing effect of CRH was submitted to desensitization. The only other study investigating CRH action on GH release in teleosts was performed in turbot *in vitro*. In this species, CRH was not active in stimulating GH release (Rousseau *et al.*, 2001). This suggests that the activity of CRH on GH in the eel may be related to the special biological cycle of this species. In this teleost, mobilization of energy stores is specially required to fullfill gonadal growth and reproductive migration (Larsen and Dufour, 1993). It is known in teleosts (Sheridan, 1994) as well as in mammals (Goodman, 1993) that cortisol and GH may interact in metabolic processes during stress or fasting by stimulating lipid mobilization. Thus, we may hypothesize that in the eel, CRH acts as a potential coordinator for activating both corticotropic and somatotropic axes during critical developmental or physiological events, such as silvering, fasting and reproductive migration. In reptiles, CRH has been shown to stimulate GH release *in vitro*, but with less potency than GHRH and TRH (Denver and Licht, 1989, 1990, 1991). In the rat, CRH has no direct effect on GH release *in vitro* by pituitary cells (Vale *et al.*, 1983; Mounier *et al.*, 1997), but a recent study demonstrated that CRH injected directly into the median eminence inhibited GH secretion (Frias *et al.*, 1999). In humans, CRH was reported to have a stimulatory action on GH release under stress situations such as fasting (Ho *et al.*, 1988) and exercise (Pyka *et al.*, 1992), and in some pathologies (depression: Lesch *et al.*, 1988; acromegaly: Pieters *et al.*, 1984; Cushing's disease: Loli *et al.*, 1998).

A brain catecholamine, dopamine, was shown to be active as a GH-releasing factor via D1-like receptors in the goldfish (Chang *et al.*, 1985, 1990; Wong *et al.*, 1992, 1993a,b), carp (Wong *et al.*, 1998b), tilapia (Melamed *et al.*, 1995, 1996), and rainbow trout (Agustsson *et al.*, 2000). In contrast, dopamine had no effect on eel GH release (Vidal *et al.*, 2000). Accordingly, none of the four D1 receptor subtypes cloned in the European eel were found to be expressed in the somatotroph area of the eel pituitary (Kapsimali *et al.*, 2000).

Recently, melatonin was shown to have a direct action on

GH release by trout pituitary cells *in vitro* (Falcon *et al.*, 2003), inducing a dose-dependent increase in GH release. However, in the presence of forskolin (adenylate cyclase activator) melatonin had an inhibitory effect at low doses and stimulatory one at high doses (Falcon *et al.*, 2003). Preliminary data in the eel, *in vivo*, indicate that implantation of melatonin induces a significant decrease in GH pituitary levels (Ph. Chemineau and S. Dufour, unpublished data).

The evolutionary occurrence of such a diversity in GH-releasing factors in teleosts may have been facilitated by the strong basal release of GH and the presence of a conserved major inhibitory control exerted by somatostatin.

Role of GH-releasing peptides in teleosts

In the 80's, the synthesis of growth-hormone-releasing peptides (GHRPs, or Growth Hormone secretagogues, GHSs) was reported by Bowers' laboratory (Bowers *et al.*, 1980; Momany *et al.*, 1981). In mammals, the effects of these synthetic peptides on GH have been extensively studied and have been shown to be rapid, to undergo desensitization and to be similar to those of endogenous GHRH (Smith *et al.*, 1997; Bowers, 1998). Their actions are mediated by a specific G-protein coupled receptor which is a distinct receptor from that of GHRH and which was, until recently, a so called orphan receptor, i.e. with no known natural ligand (Howard *et al.*, 1996; McKee *et al.*, 1997; Smith *et al.*, 1999). In 1999, Kojima *et al.* purified from rat stomach the endogenous ligand of this receptor and named it "ghrelin" (Kojima *et al.*, 1999; for review: Kojima *et al.*, 2001). Since then, ghrelin has been cloned in other vertebrate species (bullfrog: Kaiya *et al.*, 2001; chicken: Kaiya *et al.*, 2002; teleosts: Unniappan *et al.*, 2002; Kaiya *et al.*, 2003a, 2003b; Parhar *et al.*, 2003), and its sequence shows a low conservation during evolution.

Ghrelin is able to stimulate GH release in mammals when administered intravenously (rat: Kojima *et al.*, 1999; human: Takaya *et al.*, 2000; Arvat *et al.*, 2000), centrally (rat: Date *et al.*, 2000) or given to primary pituitary cells (Kojima *et al.*, 1999). Ghrelin is more potent than GHRH *in vivo* in humans (Arvat *et al.*, 2000, 2001), and in rats (Seoane *et al.*, 2000; Tolle *et al.*, 2001). Nevertheless, in rats, its GH-releasing activity *in vitro* is only comparable with (Kojima *et al.*, 1999) or less (Yamazaki *et al.*, 2002; Pinilla *et al.*, 2003) than that induced by GHRH.

In birds, administration of human ghrelin increases GH concentrations with the same potency as human GH-releasing hormone, but with less potency than TRH (Ahmed and Harvey, 2002). Administration of chicken ghrelin increases plasma GH levels in both rats and chicks, with a potency similar to that of rat or human ghrelin (Kaiya *et al.*, 2002). *In vitro*, ghrelin is a dose-related GH-releasing factor with potency comparable with that induced by human GHRH (Baudet and Harvey, 2003). In amphibians, bullfrog ghrelin stimulated the secretion of GH in dispersed bullfrog pituitary cells with potency 2-3 orders of magnitude greater than that of rat ghrelin; however, it was only minimally effective in elevating plasma GH levels following intravenous injection into rats (Kaiya *et al.*, 2001). These results indicate that, although the regulatory mechanism of ghrelin to induce GH secretion is evolutionary conserved, the structural changes in the different ghrelins result in species-specific receptor binding.

A receptor for GH secretagogues was also identified in the pufferfish and was shown to be very similar to the one observed in mammals (Palyha *et al.*, 2000). Recently, the cloning of ghrelin in goldfish (Unniappan *et al.*, 2002), in Japanese eel (Kaiya *et al.*, 2003a) and in tilapia (Parhar *et al.*, 2003) was reported. The expression of ghrelin was highest in stomach, but also found in many species in brain, intestine, kidney, spleen and gill (Unniappan *et al.*, 2002; Kaiya *et al.*, 2003a and b). In *Lota lota*, a ghrelin-immunoreactive peptide has been detected in plasma; its concentrations were low before and during reproduction, but they rose after spawning (Mustonen *et al.*, 2002). Levels of gastric ghrelin mRNA have been reported to increase dependently to age/body size in the tilapia (Parhar *et al.*, 2003).

Eel ghrelin was reported to stimulate GH release directly from organ-cultured tilapia pituitary, and to increase plasma GH concentrations in rats after intravenous injections with the same potency as rat ghrelin (Kaiya *et al.*, 2003a). In tilapia, Shepherd *et al.* (2000) have shown that the synthetic GH secretagogue, GHRP-2, stimulated GH release *in vivo* with the same potency as GHRH. Rat ghrelin was found to be able to increase GH release in tilapia *in vitro* (Riley *et al.*, 2002) and recently, the homologous, tilapia ghrelin, was cloned and shown to stimulate GH release from organ-cultured tilapia pituitary (Kaiya *et al.*, 2003b).

Peripheral control of growth hormone release and production

Conserved negative feedback by IGFs in vertebrates

The two insulin-like growth factors (IGF 1 and IGF 2), structurally related to insulin, are both highly conserved in all vertebrates (Reinecke and Collet, 1998). The two forms have been identified in gnathostomes, whereas a single molecular form of IGF has been cloned in agnathans (hagfish: Nagamaysu *et al.*, 1991; sea lamprey: Kawauchi *et al.*, 2002) and in protochordate species (amphioxus: Chan *et al.*, 1990; tunicate: McRory and Sherwood, 1997b). IGF1 is known as a major growth factor secreted by the liver under the control of GH, from mammals (Le Roith *et al.*, 2001) to lamprey (Kawauchi *et al.*, 2002). In return, IGF1 exerts an inhibitory feedback control on pituitary GH production (Le Roith *et al.*, 2001). The physiological role of IGF 2 is less well documented.

The eel IGF sequences have not yet been characterized, but messenger RNA in the liver of Japanese eel was able to hybridize with a coho salmon IGF1 probe (Duan and Hirano, 1992). IGF1 immunoreactivity was also detected in the plasma of American eel using a radioimmunassay for coho salmon IGF1 (Moriyama *et al*., 1994). In term of bioactivity, mammalian IGF1 is highly effective in stimulating sulphate uptake by branchial cartilage in the Japanese eel (Duan and Hirano, 1990; Duan and Hirano, 1992; Moriyama *et al*., 1995). We demonstrated a strong inhibitory effect of IGF1 (up to 85% of inhibition) on GH release by eel pituitary cells (Rousseau *et al*., 1998; Huang *et al*., 1999a). This effect was dose-dependent and not submitted to desensitization. A similar effect was observed with IGF2, while insulin was 1000 times less active (Rousseau *et al*., 1998). The specificity of the inhibitory action of IGFs was further demonstrated by the lack of effect of another growth factor, bFGF (Rousseau *et al*., 1998). IGF1 also strongly inhibited GH synthesis (Rousseau *et al*., 1998). Assay of GH mRNA in eel pituitary cells confirmed the inhibitory effect of IGF1 on GH expression.

Inhibitory effects of IGFs were also demonstrated on GH release in the rainbow trout (*in vivo* and *in vitro*: Perez-Sanchez *et al*., 1992; Blaise *et al*., 1995b), and on both GH release and mRNA in tilapia (Melamed *et al*., 1998; Kajimura *et al*., 2002) and hybrid striped bass (*Morone saxatilis* x *M. chrysops*) (Fruchtman *et al*., 2000) (Fig. 1). In the turbot, the type I receptor (Elies *et al*., 1999) and IGFs (1 and 2) (Duval *et al*., 2002) were cloned and in a homologous system, these IGFs were shown to inhibit with the same potencies GH release *in vitro* (Duval *et al*., 2002). These data are in agreement with the reported IGF1-binding sites to pituitary glands in rainbow trout (Blaise *et al*., 1995b) and in hybrid striped bass (Fruchtman *et al*., 2002).

In mammals, the IGF polypeptides were also shown to inhibit GH synthesis and release directly at the pituitary level (Berelowitz *et al*., 1981; Yamashita and Melmed, 1986; Namba *et al*., 1989; Weber *et al*., 1992). These data suggest that the negative feedback by IGFs represents an ancestral mechanism of regulation of the somatotropic axis highly conserved throughout vertebrate evolution (Fig. 2).

In mammals and teleosts, GH is known to regulate IGF1 (Duan, 1997). Nevertheless, for IGF2, the data are still inconsistent. In rats, IGF2 was shown to be either regulated by GH (Kim *et al*., 1993) or not (Adams *et al*., 1983), and in human, GH was suggested to be a physiological regulator of IGF2 (von Horn *et al*., 2002). In teleosts, the GH-dependence of IGF2 seems to vary according to species: stimulation by GH in rainbow trout (Shamblott *et al*., 1995) and common carp (Tse *et al*., 2002), but not in sea bream, *Sparus aurata* (Duguay *et al*., 1996) and zebrafish, *Danio rerio* (Maures *et al*., 2002). In mammals, IGF2 seems to be related to fetal growth (Daughaday and Rotwein, 1989), although in human, in contrast to rat, high IGF2 plasma levels are found in adults (Gluckman and Ambler, 1993). Its physiological role in fish has not been clearly identified. Compared to mammals and birds, in fishes, growth continues throughout a much greater period of adult life and at a lower rate (Johnston, 1999). In rabbitfish, *Siganus guttatus*, IGF2 mRNA was shown to be expressed in unfertilized eggs and during the cleavage stage, whereas IGF1 mRNA expression was first observed soon after hatching (Ayson *et al*., 2002), suggesting as in mammals that IGF2 is probably more important than IGF1 during embryogenesis and that IGF1 exerts more influence on growth and development in later life stages. Nevertheless, in other teleosts (gilthead seabream: Funkenstein *et al*., 1996, Perrot *et al*., 1999; rainbow trout: Greene and Chen, 1997; common carp: Tse *et al*., 2002), both IGF2 and IGF1 were detected in larvae, juvenile and adult fish, demonstrating a possible important role of both IGFs during growth and development throughout life in these species.

Species-variations in the feedback by thyroid hormones

Thyroid hormones (TH: T3 and T4) and GH are thought to play synergistic roles in the control of growth and developmental processes in vertebrates. The thyrotropin releasing hormone (TRH) (and CRH in some vertebrates) stimulates the synthesis and secretion of thyrotropin (TSH) by the pituitary. TSH, then, acts on the thyroid to induce the synthesis of T4, which is peripherally deiodinated into biologically active T3.

In the European eel, GH has been reported to increase circulating T3 by stimulation of peripheral 5'-monodeiodination (de Luze and Leloup, 1984). Both T3 and T4 inhibited GH release by eel somatotrophs *in vitro* in a dose-dependent manner up to a maximal inhibition of 50% (Rousseau *et al*., 2002). Other hormones acting also via the nuclear receptor superfamily, such as sexual steroids (testosterone, estradiol and progesterone) and corticosteroid (cortisol) had no effect on GH release *in vitro*, indicating a specificity of TH regulatory effect on GH (Huang *et al*., 1999b; Rousseau *et al*., 2002). This inhibitory effect of TH on GH release was in agreement with a previous study by Baker and Ingleton (1975). We also demonstrated that TH were able to inhibit GH synthesis by eel somatotrophs by decreasing GH mRNA steady levels (Rousseau *et al*., 2002). *In vivo*, we also found that administration of T3 or T4 significantly reduced pituitary and serum GH levels. Thus, the inhibitory control of GH release by TH may be viewed as a negative feedback in the interactions between somatotropic and thyrotropic axes. TH inhibition of GH may also participate in the reduction of GH production and cessation of body growth at silvering (Marchelidon *et al*., 1996).

In other teleosts, studies reported a stimulatory or no effect of TH on GH. In the carp, *in vitro*, T3 was found to increase GH mRNA levels (Farchi-Pisanty *et al*., 1995) but to have no effect on GH release (Luo and McKeown, 1991b). In the rainbow trout in which GH stimulates hepatic deiodinase activity (MacLatchy *et al*., 1990), *in vivo* treatment with T3 increased steady levels of GH mRNA, but with no alterations in pituitary or plasma levels (Moav and McKeown, 1992). Moreover, while at lower doses T3 had a marginal effect on GH release, at higher doses it reduced GH release by rainbow trout pituitary cells *in vitro* (Luo and McKeown, 1991b). In tilapia, no effect of T3 was observed *in vitro* (Nishioka *et al*., 1985). A recent study in tilapia reports that T3 stimulates hepatic IGF1 mRNA expression *in vivo* and *in vitro* (Schmid *et al*., 2003), indicating a possible negative effect of T3 on GH via IGF1.

Species-related variations in TH effects on GH were also observed among mammals. *In vitro*, whereas in the rat T3 was shown to stimulate GH mRNA levels (Samuels and Shapiro, 1976), it reduced them in bovine (Silverman *et al*., 1988) and human (Valcavi *et al*., 1992). In other vertebrates such as birds (Harvey, 1990; Denver and Harvey, 1991) and reptiles (Denver and Licht, 1988), a negative effect of TH on GH was observed. In birds, as in the eel, the inhibitory action of TH on GH may be interpreted as a negative feedback in the interactions between somatotropic and thyrotropic axes as GH is able to stimulate thyroid function (Kühn *et al*., 1987).

CONCLUSIONS

Investigation of the neuroendocrine regulation of GH in teleosts (Fig. 5) has provided important information on the conservations and variations of the somatotropic axis during vertebrate evolution (Figs 1 to 4). The major control of GH production in teleosts is inhibitory, as suggested by the high autonomous activity of somatotrophs in culture. The inhibitory controls exerted by the neurohormone, somatostatin, and by the hepatic growth factor(s) IGFs are largely conserved throughout vertebrate evolution. They could represent the basic neuroendocrine control of GH, established early during vertebrate evolution, at least in a common ancestor of the actinopterygian and the sarcopterygian lineages. In contrast, the factors which are involved in the stimulatory regulation of GH exhibit important variations among teleosts as well as among vertebrates. In teleosts, this variability of GH-releasing peptides may be related to species, biological cycle and/or physiological stages. In vertebrate evolution, PACAP may represent an ancestral GH-releasing factor, progressively replaced by GHRH in tetrapods. A high variability in the control (positive or negative) exerted by thyroid hormones on GH was also observed among teleosts as among other vertebrates.

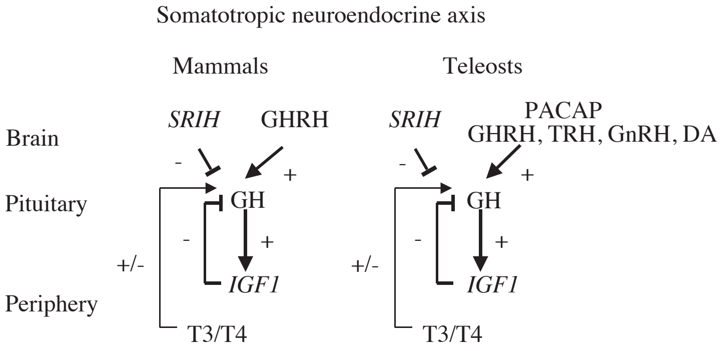

Figure 5. - Somatotropic neuroendocrine axis in mammals and in teleosts. In mammals, the regulation of GH release is primarily mediated by the dual actions of two hypothalamic hormones: GHRH stimulates, while SRIH inhibits GH release. In addition, IGF1 secreted by the liver under GH control exerts a negative feedback on GH production. Other hormones such as thyroid hormones (T3/T4) produced by the thyroid are able to either induce or inhibit GH release depending on the species. In teleosts, the inhibitory controls exerted by SRIH and by IGF1 are conserved compared to mammals. In contrast, GHRH action is not observed in all teleost species studied so far, whereas various other neurohormones may act as GH-releasing factors, depending on the species and physiological stage. PACAP may represent the ancestral GH-releasing factor in teleosts. As in mammals, thyroid hormones effect on GH release can be either stimulatory or inhibitory, according to the species.

All these data emphasize the relevance of functional studies, in addition to characterization of molecular sequences, in order to reveal the functional conservation and variations of the neuroendocrine regulatory systems in vertebrates. Investigations on additional species, representative of various groups of vertebrates, would allow to further determine the ancestral features of the somatotropic neuroendocrine axis and its functional evolution throughout vertebrate lineages.

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REFERENCES

ADAMS S.O., NISSLEY S.P., MANDWERGER S., & M.M. RECHLER, 1983. - Developmental patterns of insulin-like growth factor I and II synthesis and regulation in rat fibroblasts. *Nature*, 302: 150-153.

ADAMS B.A., TELLO J.A., ERCHEGYI J., WARBY C., HONG D.J., AKINSANYA K.O., MACKIE G.O., VALE W., RIVIER J.E. & N.M. SHERWOOD, 2003. - Six novel gonadotropin-releasing hormones are encoded as triplets on each of two genes in the protochordate, *Ciona intestinalis*. *Endocrinology*, 144: 1907-1919.

AGUSTSSON T., EBBESSON L.O.A. & B.T. BJORNSSON, 2000. - Dopaminergic innervation of the rainbow trout pituitary and stimulatory effect of dopamine on growth hormone secretion *in vitro*. *Comp. Biochem. Physiol.*, 127A: 355-364.

AHMED S. & S. HARVEY, 2002. - Ghrelin: A hypothalamic GH-releasing factor in domestic fowl (*Gallus domesticus*). *J. Endocrinol.*, 172: 117-125.

ALEXANDRE D., ANOUAR Y., JEGOU S. & H. VAUDRY, 2000. - Structure and distribution of the mRNAs encoding pituitary adenylate cyclase-activating polypeptide and growth hormone-releasing hormone-like peptide in the frog *Rana ridibunda*. *J. Comp. Neurol.*, 421: 234-246.

ARVAT E., DI VITO L., BROGLIO F., PAPOTTI M., MUCCIOLI G., DIEGUEZ C., CASANUEVA F.F., DEGHENGHI R., CAMANNI F. & E. GHIGO, 2000. - Preliminary evidence that ghrelin, the natural GH secretagogue (GHS)-receptor ligand, strongly stimulates GH secretion in humans. *J. Endocrinol. Invest.*, 23: 493-495.

ARVAT E., MACCARIO M., DI VITO L., BROGLIO F., BENSO A., GOTTERO C., PAPOTTI M., MUCCIOLI G., DIEGUEZ C., CASANUEVA F.F., DEGHENGHI R., CAMANNI F. & E. GHIGO, 2001. - Endocrine activities of ghrelin, a natural growth hormone secretagogue (GHS), in humans: Comparison and interactions with hexarelin, a nonnatural peptidyl GHS, and GH-releasing hormone. *J. Clin. Endocrinol. Metab.*, 86: 1169-1174.

AYSON F.G., DE JESUS E.G.T., MORIYAMA S., HYODO S., FUNKENSTEIN B., GERTLER A. & H. KAWAUCHI, 2002. - Differential expression of insulin-like growth factor I and II mRNAs during embryogenesis and early larval development in rabbitfish, *Siganus guttatus*. *Gen. Comp. Endocrinol.*, 126: 165-174.

BAKER B.I. & P.M. INGLETON, 1975. - Secretion of prolactin and growth hormone by teleost pituitaries *in vitro*. II. Effect of salt concentration during long-term organ culture. *J. Comp. Physiol.*, 100: 269-282.

BAUDET M.L. & S. HARVEY, 2003. - Ghrelin-induced GH secretion in domestic fowl *in vivo* and *in vitro*. *J. Endocrinol.*, 179: 97-105.

BERELOWITZ M., SZABO M., FROHMAN L., FIRESTONE S., CHU L. & L. HINTZ, 1981. - Somatomedin-C mediates growth hormone negative feedback by effects on both the hypothalamus and the pituitary. *Science*, 212: 1279-1280.

BJORNSSON B.T., 1997. - The biology of salmon growth hormone: From daylight to dominance. *Fish Physiol. Biochem.*, 17: 9-24.

BLAISE O., LE BAIL P.Y. & C. WEIL, 1995a. - Lack of gonadotropin releasing-hormone action on *in vivo* and *in vitro* growth hormone release, in rainbow trout (*Oncorhynchus mykiss*). *Comp. Biochem. Physiol.*, 110C: 133-141.

BLAISE O., WEIL C. & P.Y. LE BAIL, 1995b. - Role of IGF1 in the control of GH secretion in rainbow trout (*Oncorhynchus mykiss*). *Growth Regul.*, 5: 142-150.

BLUET-PAJOT M., EPELBAUM J., GOUDJI D., HAMMOND C. & C. KORDON, 1998. - Hypothalamic and hypophyseal regulation of growth hormone secretion. *Cell. Mol. Neurobiol.*, 18: 101-123.

BOSMA P., KOLK S., REBERS F., LESCROART O., ROELANTS I., WILLEMS P. & R. SCHULZ, 1997. - Gonadotrophs but not somatotrophs carry gonadotropin-releasing hormone receptors: Receptor localisation, intracellular calcium, and gonadotropin and GH release. *J. Endocrinol.*, 152: 437-446.

BOWERS C.Y., MOMANY F., REYNOLDS G.A., CHANG D., HONG A. & K. CHANG, 1980. - Structure-activity relationships of a synthetic pentapeptide that specifically releases growth hormone *in vitro*. *Endocrinology*, 106: 663-667.

BOWERS C.Y., 1998. - Growth hormone-releasing peptide (GHRP). *Cell. Mol. Life Sci.*, 54: 1316-1329.

BRAZEAU P., VALE W.W., BURGUS R., LING N., BUTCHER M., RIVIER J. & R. GUILLEMIN, 1973. - Hypothalamic peptide that inhibits the secretion of immunoreactive pituitary growth hormone. *Science*, 179: 77-79.

CAROLSFELD J., POWELL J.F.F., PARK M., FISCHER W.H., CRAIG A.G., CHANG J.P., RIVIER J.E. & N.M. SHERWOOD, 2000. - Primary structure and function of three gonadotropin-releasing hormones, including a novel form, from an ancient teleost, herring. *Endocrinology*, 141: 505-512.

CHAN S.J., CAO Q.P. & D.F. STEINER, 1990. - Evolution of the insulin superfamily: cloning of a hybrid insulin/insulin-like growth fator cDNA from amphioxus. *Proc. Natl. Acad. Sci. USA*, 87: 9319-9323.

CHAN K., YU K., RIVIER J. & B. CHOW, 1998. - Identification and characterization of a receptor from goldfish specific for a teleost growth-hormone releasing hormone-like peptide. *Neuroendocrinology*, 68: 44-56.

CHANG J.P., MARCHANT T.A., COOK A.F., NAHORNIAK C.S. & R.E. PETER, 1985. - Influence of catecholamines on growth hormone release in female goldfish, *Carassius auratus*. *Neuroendocrinology*, 40: 463-470.

CHANG J.P. & R. DE LEEUW R., 1990. - *In vitro* goldfish growth hormone responses to gonadotropin-releasing hormone: possible roles of extracellular calcium and arachidonic acid metabolism? *Gen. Comp. Endocrinol.*, 80: 155-164.

CHANG J.P., YU K.L., WONG A.O. & R.E. PETER, 1990. - Differential actions of dopamine receptor subtypes on gonadotropin and growth hormone release *in vitro* in goldfish. *Neuroendocrinology*, 51: 664-674.

COLLIE N.L. & J.J. STEVENS, 1985. - Hormonal effects of L-proline transport in coho salmon (*Oncorhynchus kisutch*) intestine. *Gen. Comp. Endocrinol.*, 59: 399-409.

COMPANY R., ASTOLA A., PENDON C., VALDIVIA M.M. & J. PEREZ-SANCHEZ, 2001. - Somatotropic regulation of fish growth and adiposity: Growth hormone (GH) and somatolactin (SL) relationship. *Comp. Biochem. Physiol.*, 130C: 435-445.

CONLON J.M., DEACON C.F., HAZON N., HENDERSON I.W. & L. THIM, 1988. - Somatostatin-related and glucagon-related peptides with unusual structural features from the European eel (*Anguilla anguilla*). *Gen. Comp. Endocrinol.*, 72: 181-189.

CONLON J.M., TOSTIVINT H. & H. VAUDRY, 1997. - Somatostatin- and urotensin II-related peptides: Molecular diversity and evolutionary perspectives. *Regul. Pept.*, 69: 95-103.

COOK A.F. & R.E. PETER, 1984. - The effects of somatostatin on serum growth hormone levels in the goldfish, *Carassius auratus*. *Gen. Comp. Endocrinol.*, 54: 109-113.

COOK H., BERKENBOSCH J., FERNHOUT M., YU K., PETER R., CHANG J. & J. RIVIER, 1991. - Demonstration of gonadotropin-releasing hormone receptors on gonadotrophs and somatotrophs of the goldfish: An electron microscope study. *Regul. Pept.*, 36: 369-378.

DATE Y., MURAKAMI N., KOJIMA M., KUROIWA T., MATSUKURA S., KANGAWA K. & M. NAKAZATO, 2000. - Central effects of a novel acylated peptide, ghrelin, on growth hormone release in rats. *Biochem. Biophys. Res. Commun.*, 275: 477-480.

DAUGHADAY W. & P. ROTWEIN, 1989. - Insulin-like growth factors I and II. Peptide, messenger ribonucleic acid and gene structures, serum and tissue concentrations. *Endocr. Rev.*, 10: 68-88.

DE LUZE A. & J. LELOUP, 1984. - Fish growth hormone enhances peripheral conversion of thyroxine to triiodothyronine in the eel (*Anguilla anguilla* L.). *Gen. Comp. Endocrinol.*, 56: 308-312.

DE PINNA M.C.C., 1996. - Teleostean monophyly. *In*: Interrelationships of Fishes (Stiassny M.L.J., Parenti L.R. & G.D. Johnson, eds), pp. 147-162. New York: Academic Press.

DEGGE R.B., UPTON Z., SOOLE K., COLLET C. & N. RICHARDSON, 2000. - Comparison of recombinant barramundi and human insulin-like growth factor (IGF)-I in juvenile barramundi (*Lates calcarifer*): *In vivo* metabolic effects, association with circulating IGF-binding proteins and tissue localization. *Gen. Comp. Endocrinol.*, 117: 395-403.

DENVER R. & P. LICHT, 1988. - Thyroid hormones act at the level of the pituitary to regulate thyrotropin and growth hormone secretion in hatchling slider turtles (*Pseudemys scripta elegans*). *J. Exp. Zool.*, 247: 146-154.

DENVER R. & P. LICHT, 1989. - Neuropeptides influencing *in vitro* pituitary hormone secretion in hatchling turtles. *J. Exp. Zool.*, 251: 306-315.

DENVER R. & P. LICHT, 1990. - Modulation of neuropeptide-stimulated pituitary hormone secretion in hatchling turtles. *Gen. Comp. Endocrinol.*, 77: 107-115.

DENVER R. & P. LICHT, 1991. - Several hypothalamic peptides stimulate thyrotropin and growth hormone secretion by adult pituitary glands. *Comp. Biochem. Physiol.*, 100A: 603-606.

DIEZ J., GIANNICO G., McLEAN E. & E. DONALDSON, 1992. - The effects of somatostatins (SRIF-14, 25 and 28), galanin and anti-SRIF on plasma growth hormone levels in coho salmon (*Oncorhynchus kisutch* Walbaum). *J. Fish Biol.*, 40: 887-893.

DUAN C., 1997. - The insulin-like growth factor system and its biological actions in fish. *Am. Zool.*, 37: 491-503.

DUAN C. & T. HIRANO, 1990. - Stimulation of 35S-sulfate by mammalian insulin-like growth factor I and II in cultured cartilages of the Japanese eel, *Anguilla japonica*. *J. Exp. Zool.*, 256: 347-350.

DUAN C. & T. HIRANO, 1992. - Effects of insulin-like growth factor I and insulin on the *in vitro* uptake of sulphate by eel branchial cartilage: Evidence for the presence of independent hepatic and pancreatic sulphation factors. *J. Endocrinol.*, 133: 211-219.

DUGUAY S.J., LAI-ZHANG J., STEINER D.F., FUNKENSTEIN B. & S.J. CHAN, 1996. - Developmental and tissue-regulated expression of IGF1 and IGF2 mRNAs in *Sparus aurata*. *Gen. Comp. Endocrinol.*, 16: 123-132.

DUVAL H., ROUSSEAU K., ELIES G., LE BAIL P-Y., DUFOUR S., BOEUF G. & D. BOUJARD, 2002. - Cloning, characterization and comparative activity of turbot IGF-I and IGF-II. *Gen. Comp. Endocrinol.*, 126: 269-278.

ELIES G., DUVAL H., BONNEC G., WOLFF J., BOEUF G. & D. BOUJARD, 1999. - Turbot insulin and insulin-like growth factor type 1 receptors: cDNA cloning and mRNA expression. *Mol. Cell. Endocrinol.*, 158: 173-185.

EVANS D.H., 2002. - Cell signaling and ion transport across the fish gill epithelium. *J. Exp. Zool.*, 293: 336-347.

FALCON J., BESSEAU L., FAZZARI D., ATTIA J., GAILDRAT P., BEAUCHAUD M. & G. BOEUF, 2003. - Melatonin modulates secretion of growth hormone and prolactin by trout pituitary glands and cells in culture. *Endocrinology*, 144: 4648-4658.

FARCHI-PISANTY O., HACKETT P. Jr & B. MOAV, 1995. - Regulation of fish growth hormone transcription. *Mol. Mar. Biol. Biotechnol.*, 4: 215-223.

FARMANFARMAIAN A. & L.Z. SUN, 1999. - Growth hormone effects on essential amino acid absorption, muscle amino acid profile, N-retention and nutritional requirements of striped bass hybrids. *Genet. Anal.*, 15: 107-113.

FOSTER A., HOULIHAN D., GRAY C., MEDALE F., FAUCONNEAU B., KAUSHIK S. & P.-Y. LE BAIL, 1991. - The effects of ovine growth hormone on protein turnover in rainbow trout. *Gen. Comp. Endocrinol.*, 82: 111-120.

FRIAS J., RUIZ E. & E. ORTEGA, 1999. - Effect of corticotrophin releasing factor injected into the median eminence on growth hormone secretion in male rats. *Neurochem. Res.*, 24: 715-718.

FRUCHTMAN S., JACKSON L. & R. BORSKI, 2000. - Insulin-like growth factor I disparately regulates prolactin and growth hormone synthesis and secretion: Studies using the teleost pituitary model. *Endocrinology*, 141: 2886-2894.

FRUCHTMAN S., McVEY D.C. & R.J. BORSKI, 2002. - Characterization of pituitary IGF-I receptors: Modulation of prolactin and growth hormone. *Am. J. Physiol.*, 283: R468-476.

FRYER J.N., NISHIOKA R.S. & H.A. BERN, 1979. - Somatostatin inhibition of teleost growth hormone secretion. *Gen. Comp. Endocrinol.*, 39: 244-246.

FUNKENSTEIN B., SHEMER R., AMULY R. & I. COHEN, 1996. - Nucleotide sequence of the promoter region of *Sparus aurata* insulin-like growth factor I gene and expression of IGF-I in eggs and embryos. *Mol. Mar. Biol. Biotechnol.*, 5: 43-51.

GLUCKMAN P. & G. AMBLER, 1993. - What is the function of circulating insulin-like growth factor II in postnatal life? *Mol. Cell. Endocrinol.*, 92: C1-C3.

GOODMAN H., 1993. - Growth hormone and metabolism. *In*: The Endocrinology of Growth, Development and Metabolism in Vertebrates (Schreibman M.P., Scanes C.G. & P.K.T. Pang, eds), pp. 93-115. San Diego: Academic Press.

GOTH M., LYONS C.E., CANNY B.J. & M.O. THORNER, 1992. - Pituitary adenylate cyclase activating polypeptide, growth hormone (GH)-releasing peptide and GH-releasing hormone stimulate GH release through distinct pituitary receptors. *Endocrinology*, 130: 939-944.

GREENE M.W. & T.T. CHEN, 1997. - Temporal expression pattern of insulin-like growth factor mRNA during embryonic development in a teleost, rainbow trout (*Oncorhynchus mykiss*). *Mol. Mar. Biol. Biotechnol.*, 6: 144-151.

HALL T.R. & A. CHADWICK, 1976. - Effects of growth hormone inhibiting factor (somatostatin) on the release of growth hormone and prolactin from pituitaries of the domestic fowl *in vitro*. *J. Endocrinol.*, 68: 163-164.

HALL T.R. & A. CHADWICK, 1984. - Effects of synthetic mammalian thyrotropin releasing hormone, somatostatin and dopamine on the secretion of prolactin and growth hormone from amphibian and reptilian pituitary glands incubated *in vitro*. *J. Endocrinol.*, 102: 175-180.

HARRIS J. & D. BIRD, 2000. - Modulation of the fish immune system by hormones. *Vet. Immunol. Immunopathol.*, 77: 163-176.

HARVEY S., 1990. - Thyrotropin-releasing hormone: a growth hormone-releasing factor. *J. Endocrinol.*, 125: 345-358.

HARVEY S., SCANES C.G., CHADWICK A. & N.J. BOLTON, 1978. - The effect of thyrotropin-releasing hormone (TRH) and somatostatin (GHRIH) on growth hormone and prolactin secretion *in vitro* and *in vivo* in the domestic fowl (*Gallus domesticus*). *Neuroendocrinology*, 26: 249-260.

HIGGS D.A., DONALDSON E.M., DYE H.M. & J.R. McBRIDE, 1975. - A preliminary investigation of the effect of bovine growth hormone on growth and muscle composition of coho salmon (*Oncorhynchus kisutch*). *Gen. Comp. Endocrinol.*, 27: 240-253.

HO K., VEDHUIS J., JOHNSON M., FURNALETTO R., EVANS R., ALBERTI K. & M. THORNER, 1988. - Fasting enhances growth hormone secretion and amplifies the complex rhythms of growth hormone secretion in man. *J. Clin. Invest.*, 81: 968-975.

HOWARD A.D., FEIGHNER S.D., CULLY D.F., ARENA J.P., LIBERATOR P.A., ROSENBLUM C.I., HAMELIN M., HRENIUK D.L., PALYHA O.C., ANDERSON J. *et al.*, 1996. - A receptor in pituitary and hypothalamus that functions in growth hormone release. *Science*, 273: 974-977.

HU Z., LELIEVRE V., TAM J., CHENG J.W., FUENZALIDA G., ZHOU X. & J.A. WASCHEK, 2000. - Molecular cloning of growth hormone releasing hormone/pituitary adenylate cyclase-activating polypeptide in the frog *Xenopus laevis*: brain distribution and regulation after castration. *Endocrinology*, 141: 3366-3376.

HUANG Y-S., ROUSSEAU K., LE BELLE N., VIDAL B., BURZAWA-GERARD E., MARCHELIDON J. & S. DUFOUR, 1999a. - Opposite effects of insulin-like growth factors (IGFs) on gonadotropin (GtH-II) and growth hormone (GH) production by primary culture of European eel (*Anguilla anguilla*) pituitary cells. *Aquaculture*, 177: 73-83.

HUANG Y-S., ROUSSEAU K., SBAIHI M., LE BELLE N., SCHMITZ M. & S. DUFOUR, 1999b. - Cortisol selectively stimulates pituitary gonadotropin ß-subunit in a primitive teleost, *Anguilla anguilla*. *Endocrinology*, 140: 1228-1235.

INUI Y. & H. ISHIOKA, 1985. - *In vivo* and *in vitro* effects of growth hormone on the incorporation of [14C] leucine into protein of liver and muscle of the eel. *Gen. Comp. Endocrinol.*, 59: 295-300.

JEANDEL L., OKUNO A., KOBAYASHI T., KIKUYAMA S., TOSTIVINT H., LIHRMANN I., CHARTREL N., CONLON J.M., FOURNIER A., TONON M.C. & H. VAUDRY, 1998. - Effects of the two somatostatin variants somatostatin-14 and [Pro2, Met13]somatostatin-14 on receptor binding, adenylyl cyclase activity and growth hormone release from the frog pituitary. *J. Neuroendocrinol.*, 10: 187-192.

JOHNSTON I.A., 1999. - Muscle development and growth: potential implications for flesh quality in fish. *Aquaculture*, 177: 99-115.

JONSSON E., JOHNSSON J.I. & B.T. BJORNSSON, 1998. - Growth hormone increases aggressive behavior in juvenile rainbow trout. *Horm. Behav.*, 33: 9-15.

JONSSON E., JOHANSSON V., BJORNSSON B.T. & S. WINBERG, 2003. - Central nervous system actions of growth hormone on brain monamine levels and behavior of juvenile rainbow trout. *Horm. Behav.*, 43: 367-374.

KAGABU Y., MISHIBA T., OKINO T. & T. YANAGISAWA, 1998. - Effects of thyrotropin-releasing hormone and its metabolites, cyclo (His-Pro) and TRH-OH, on growth hormone and prolactin synthesis in primary cultured pituitary cells of the common carp, *Cyprinus carpio*. *Gen. Comp. Endocrinol.*, 111: 395-403.

KAIYA H., KOJIMA M., HOSODA H., KODA A., YAMAMOTO K., KITAJIMA Y., MATSUMOTO M., MINAMITAKE Y., KIKUYAMA S. & K. KANGAWA, 2001. - Bullfrog ghrelin is modified by n-octaneic acid at its third threonine residue. *J. Biol. Chem.*, 276: 40441-40448.

KAIYA H., VAN DER GEYTEN S., KOJIMA M., HOSODA H., KITAJIMA Y., MATSUMOTO M., GEELISSEN S., DARRAS V.M. & K. KANGAWA, 2002. - Chicken ghrelin: Purification, cDNA cloning and biological activity. *Endocrinology*, 143: 3454-3463.

KAIYA H., KOJIMA M., HOSODA H., RILEY L.G., HIRANO T., GRAU E.G. & K. KANGAWA, 2003a. - Amidated fish ghrelin: purification, cDNA cloning in the Japanese eel and its biological activity. *J. Endocrinol.*, 176: 415-423.

KAIYA H., KOJIMA M., HOSODA H., RILEY L.G., HIRANO T., GRAU E.G. & K. KANGAWA, 2003b. - Identification of tilapia ghrelin and its effects on growth hormone and prolactin release in the tilapia. *Comp. Biochem. Physiol.*, 135B: 421-429.

KAJIMURA S., UCHIDA K., YADA T., HIRANO T., AIDA K. & G.E. GRAU, 2002. - Effects of insulin-like growth factors (IGF-I and -II) on growth hormone and prolactin release and gene expression in euryhaline tilapia, *Oreochromis mossambicus*. *Gen. Comp. Endocrinol.*, 127: 223-231.

KAPSIMALI M., VIDAL B., GONZALEZ A., DUFOUR S. & P. VERNIER, 2000. - Distribution of the mRNA encoding the four dopamine D1 receptor subtypes in the brain of the European eel (*Anguilla anguilla*): Comparative approach to the function of D1 receptors in vertebrates. *J. Comp. Neurol.*, 419: 320-343.

KAWAUCHI H., SUZUKI K., YAMAZAKI T., MORIYAMA S., NOZAKI M., YAMAGUCHI K., TAKAHASHI A., YOUSON J. & S.A. SOWER, 2002. - Identification of growth hormone in the sea lamprey, an extant representative of a group of the most ancient vertebrates. *Endocrinology*, 143: 4916-4921.

KIM J.D., NANTO-SALONEN K., SZCZEPANKIEWICZ J.R., ROSENFELD R.G. & G.F. GLASSCOCK, 1993. - Evidence for pituitary regulation of somatic growth, insulin-like growth factors-I and -II, and their binding proteins in the fetal rat. *Pediatr. Res.*, 33: 144-151.

KLAUSEN C., CHANG J.P. & H.R. HABIBI, 2001. - The effect of gonadotropin-releasing hormone on growth hormone and gonadotropin subunit gene expression in the pituitary of goldfish, *Carassius auratus*. *Comp. Biochem. Physiol.*, 129B: 511-516.

KLAUSEN C., CHANG J.P. & H.R. HABIBI, 2002. - Time- and dose-related effects of gonadotropin-releasing hormone on growth hormone and gonadotropin subunit gene expression in the goldfish pituitary. *Can. J. Physiol. Pharmacol.*, 80: 915-924.

KOJIMA M., HOSODA H., DATE Y., KAKAZATO M., MATSUO H. & K. KANGAWA, 1999. - Ghrelin is a growth-hormone releasing acylated peptide from stomach. *Nature*, 402: 656-660.

KOJIMA M., HOSODA H., MATSUO H. & K. KANGAWA, 2001. - Ghrelin: discovery of the natural endogenous ligand for the growth hormone secretagogue receptor. *Trends Endocrinol. Metab.*, 12: 118-122.

KUHN E., VERHEYEN G., CHIASSON R., HUTS C., HUYBRECHTS L., VAN DEN STEEN P. & E. DECUYPERE, 1987. - Growth hormone stimulates the peripheral conversion of thyroxine into triiodothyronine by increasing the liver 5'-monodeiodinase activity in the fasted and normal fed chickens. *Horm. Metab. Res.*, 19: 304-308.

LARSEN L.O. & S. DUFOUR, 1993. - Growth, reproduction and death in lampreys and eels. *In*: Fish Ecophysiology (Rankin J.C. & B. Franck, eds), pp. 72-104. London: Chapman and Hall.

LEATHERLAND J.F. & R.N. NUTI, 1981. - Effects of bovine growth hormone on plasma FFA concentrations and liver, muscle and carcass lipid content in rainbow trout, *Salmo gairdneri* Richardson. *J. Fish Biol.*, 19: 487-498.

LE BAIL P.-Y., 1988. - Growth-reproduction interaction in salmonids. *In*: Reproduction in Fish: Basic and Applied Aspects in Endocrinology and Genetics, pp. 91-108. Paris: edit. INRA

LE BAIL P.-Y., SUMPTER J.P., CARRAGHER J.F., MOUROT B., NIU P.D. & C. WEIL, 1991. - Development and validation of a highly sensitive radioimmunoassay for Chinook salmon (*Oncorhynchus tshawytscha*) growth hormone. *Gen. Comp. Endocrinol.*, 83: 75-85.

LE GAC F., BLAISE O., FOSTIER A., LE BAIL P.-Y., LOIR M., MOUROT B. & C. WEIL, 1993. - Growth hormone (GH) and reproduction: A review. *Fish Physiol. Biochem.*, 11: 219-232.

LE ROITH D., BONDY C., YAKAR S., LIU J.-L. & A. BUTLER, 2001. - The somatomedin hypothesis. *Endoc. Rev.*, 22: 53-74.

LESCH K., LAUX G., SCHULTE H., PFULLER H. & H. BECKMANN, 1988. - Abnormal responsiveness of growth hormone to human corticotropin-releasing hormone in major depressive disorder. *J. Affect. Disord.*, 14: 245-250.

LESCROART O., ROELANTS I., MIKOLAJCYK T., BOSMA P.T., SCHULZ R.W., KUHN E.R. & F. OLLEVIER, 1996. - A radioimmunoassay for African catfish growth hormone: Validation and effects of substances modulating the release of growth hormone. *Gen. Comp. Endocrinol.*, 104: 147-155.

LEUNG F.C. & J.E. TAYLOR, 1983. - *In vivo* and *in vitro* stimulation of growth hormone release in chickens by synthetic human pancreatic growth hormone release factor (hpGRFs). *Endocrinology*, 113: 1913-1915.

LEUNG T., NG T. & N. WOO, 1991. - Metabolic effects of bovine growth hormone in the tilapia *Oreochromis mossambicus*. *Comp. Biochem. Physiol.*, 99A:633-636.

LEUNG M.Y., TSE L.Y., YU K.L., CHOW B.K.C. & A.O.L. WONG, 1999. - Molecular cloning and tissue distribution of PACAP in the goldfish. *In*: Recent Progress in Molecular and Comparative Endocrinology (Kwon H.B., Joss J.M.P. & S. Ishii, eds), pp. 383-388. Kwangju: Hormone Research Center, Chonman National Univ.

LI W.S., LIN H.R. & A.O. WONG, 2002. - Effects of gonadotropin-releasing hormone on growth hormone secretion and gene expression in common carp pituitary. *Comp. Biochem. Physiol.*, 132B: 335-341.

LIN X.W. & R.E. PETER, 2001. - Somatostatins and their receptors in fish. *Comp. Biochem. Physiol.*, 129B: 543-550.

LIN X.W. & R.E. PETER, 2003. - Somatostatin-like receptors in goldfish: Cloning of four new receptors. *Peptides*, 24: 53-63.

LIN X.W., LIN H.R. & R.E. PETER, 1993. - The regulatory effects of thyrotropin-releasing hormone on growth hormone secretion from the pituitary of common carp *in vitro*. *Fish Physiol. Biochem.*, 11: 71-76.

LIN X.W., OTTO C.J. & R.E. PETER, 1998. - Evolution of neuroendocrine peptide systems: Gonadotropin-releasing hormone and somatostatin. *Comp. Biochem. Physiol.*, 119C: 375-388.

LIN X., OTTO C.J. & R.E. PETER, 1999. - Expression of three distinct somatostatin messenger ribonucleic acids (mRNAs) in goldfish brain: Characterization of the complementary deoxyribonucleic acids, distribution and seasonal variation of the mRNAs, and action of a somatostatin-14 variant. *Endocrinology*, 140: 2089-2099.

LIN X., VOLKOFF H., NARNAWARE Y., BERNIER N.J., PEYON P. & R.E. PETER, 2000. - Brain regulation of feeding behavior and food intake in fish. *Comp. Biochem. Physiol.*, 126A: 415-434.

LOLI P., BOCCARDI E., BRANCA V., BRAMERIO M., BARBERIS M., LOSA M., TERRENI M.T., LODRINI S., POLLO B. & F. VIGNATI, 1998. - Growth hormone and prolactin responses to corticotrophin-releasing hormone in patients with Cushing's disease: A paracrine action of the adenomatous corticotropic cells? *Clin. Endocrinol.*, 49: 433-439.

LOVEJOY D. & R. BALMENT, 1999. - Evolution and physiology of the corticotrophin-releasing factor (CRF) family of neuropeptides in vertebrates. *Gen. Comp. Endocrinol.*, 115: 1-22.

LUO D., McKEOWN B.A., RIVIER J. & W. VALE, 1990. - *In vitro* responses of rainbow trout (*Oncorhynchus mykiss*) somatotrophs to carp growth hormone-releasing factor (GRF) and somatostatin. *Gen. Comp. Endocrinol.*, 80: 288-298.

LUO D. & B. McKEOWN, 1991a. - Interaction of carp growth hormone-releasing factor and somatostatin on *in vitro* release of growth hormone in rainbow trout (*Oncorhynchus mykiss*). *Neuroendocrinology*, 54: 359-364.

LUO D. & B.A. McKEOWN, 1991b. - The effect of thyroid hormone and glucocorticoids on carp growth hormone-releasing factor (GRF)-induced growth hormone (GH) release in rainbow trout (*Oncorhynchus mykiss*). *Comp. Biochem. Physiol.*, 99A: 621-626.

MACLATCHY D., KAWAUCHI H. & J. EALES, 1990. - Stimulation of hepatic thyroxine 5'-deiodinase activity in rainbow trout (*Oncorhynchus mykiss*) by pacific salmon growth hormone. *Comp. Biochem. Physiol.*, 101A: 689-691.

MADIGOU T., MANANOS-SANCHEZ E., HULSHOF S., ANGLADE I., ZANUY S. & O. KAH, 2000. - Cloning, tissue distribution and central expression of the gonadotropin-releasing hormone receptor in the rainbow trout (*Oncorhynchus mykiss*). *Biol. Reprod.*, 63: 1857-1866.

MARCHANT T.A. & R.E. PETER, 1989. - Hypothalamic peptides influencing growth hormone secretion in the goldfish, *Carassius auratus*. *Fish Physiol. Biochem.*, 7: 133-139.

MARCHANT T.A., FRASER R.A., ANDREWS P.C. & R.E. PETER, 1987. - The influence of mammalian and teleost somatostatins on the secretion of growth hormone from goldfish (*Carassius auratus* L.) pituitary fragments *in vitro*. *Regul. Pept.*, 17: 41-52.

MARCHANT T., CHANG J., NAHORNIAK C. & R. PETER, 1989. - Evidence that gonadotropin-releasing hormone also functions as a growth hormone-releasing factor in the goldfish. *Endocrinology*, 124: 2509-2518.

MARCHELIDON J., SCHMITZ M., HOUDEBINE L.M., VIDAL B., LE BELLE N. & S. DUFOUR, 1996. - Development of a radioimmunoassay for European eel growth hormone and application to the study of silvering and experimental fasting. *Gen. Comp. Endocrinol.*, 102: 360-369.

MARTINEZ-FUENTES A., GONZALEZ DE AGUILAR J., LACUISSE S., KIKUYAMA S., VAUDRY H. & F. GARCIA-NAVARRO, 1994. - Effects of frog pituitary adenylate cyclase activating polypeptide (PACAP) on amphibian pituitary cells. *In*: Vasoactive Intestinal Peptide, Pituitary Adenylate Cyclase-Activating Polypeptide and Related Regulatory Peptides: From Molecular Biology to Clinical Applications (Rosselin G., ed.), pp. 376-380. Singapore: World Scientific.

MAURES T., CHAN S.J., XU B., SUN H., DING J. & C. DUAN, 2002. - Structural, biochemical and expression analysis of two distinct insulin-like growth factor I receptors and their ligands in zebrafish. *Endocrinology*, 143: 1858-1871.

McCORMICK S.D., 2002. - Endocrine control of osmoregulation in teleost fish. *Am. Zool.*, 41: 781-794.

McKEE K.K., PALYHA O.C., FEIGHNER S.D., HRENIUK D.L., TAN C.P., PHILLIPS M.S., SMITH R.G., VAN DER PLOEG L.H. & A.D. HOWARD, 1997. - Molecular analysis of rat pituitary and hypothalamic growth hormone secretagogue receptors. *Mol. Endocrinol.*, 11: 415-423.

McKEOWN B., LEATHERLAND J. & T. JOHN, 1975. - The effect of growth hormone and prolactin on the mobilization of free fatty acids and glucose in the kokanee salmon, *Oncorhynchus nerka*. *Comp. Biochem. Physiol.*, 50B: 425-430.

McRORY J. & N.M. SHERWOOD, 1997a. - Two protochordate genes encode pituitary adenylate cyclase-activating polypeptide and related family members. *Endocrinology*, 138: 2380-2390.

McRORY J.E. & N.M. SHERWOOD, 1997b. - Ancient divergence of insulin and insulin-like growth factor. *DNA Cell Biol.*, 16: 939-949.

McRORY J., PARKER D., NGAMVONGCHON S. & N. SHERWOOD, 1995. - Sequence and expression of cDNA for pituitary adenylate cyclase activating polypeptide (PACAP) and growth hormone-releasing hormone (GHRH)-like peptide in catfish. *Mol. Cell. Endocrinol.*, 108: 169-177.

McRORY J., PARKER R. & N. SHERWOOD, 1997. - Expression and alternative processing of a chicken gene encoding both growth hormone-releasing hormone and pituitary adenylate cyclase-activating polypeptide. *DNA Cell Biol.*, 16: 95-102.

MELAMED P., ELIAHU N., LEVAVI-SIVAN B., OFIR M., FARCHI-PISANTY O., RENTIER-DELERUE F., SMAL J., YARON Z. & Z. NAOR, 1995. - Hypothalamic and thyroidal regulation of growth hormone in *Tilapia*. *Gen. Comp. Endocrinol.*, 97: 13-30.

MELAMED P., GUR G., ELIZUR A., ROSENFELD H., SIVAN B., RENTIER-DELERUE F. & Z. YARON, 1996. - Differential effects of gonadotropin releasing hormone, dopamine and somatostatin and their second messengers on mRNA levels of gonadotropin IIß subunit and growth hormone in the teleost fish, tilapia. *Neuroendocrinology*, 64: 320-328.

MELAMED P., ROSENFELD H., ELIZUR A. & Z. YARON, 1998. - Endocrine regulation of gonadotropin and growth hormone gene transcription in fish. *Comp. Biochem. Physiol.*, 119C: 325-338.

MIYATA A., ARIMURA A., DAHL R., MINAMINO N., UEHARA A., JIANG L., CULLER M. & D. COY, 1989. - Isolation of a novel 38-residues hypothalamic polypeptide which stimulates adenylate cyclase in pituitary cells. *Biochem. Biophys. Res. Comm.*, 164: 567-574.

MIYATA A., JIANG L., DAHL R., KITADA C., KUBO K., FUJINO M., MINAMINO N. & A. ARIMURA, 1990. - Isolation of a neuropeptide corresponding to the N-terminal 27 residues of the pituitary adenylate cyclase-activating polypeptide with 38-residues (PACAP 38). *Biochem. Biophys. Res. Comm.*, 170: 643-648.

MOAV B. & B. McKEOWN, 1992. - Thyroid hormone increases transcription of growth hormone mRNA in rainbow trout pituitary. *Horm. Metab. Res.*, 24: 10-14.

MOMANY F.A., BOWERS C.Y., REYNOLDS G.A., CHANG D., HONG A. & K. NEWLANDER, 1981. - Design, synthesis and biological activity of peptides which release growth hormone *in vitro*. *Endocrinology*, 108: 31-39.

MOMMSEN T.P., 2001. - Paradigms of growth in fish. *Comp. Biochem. Physiol.*, 129B: 207-219.

MONTERO M., VIDAL B., KING J.A., TRAMU G., VANDESANDE F., DUFOUR S. & O. KAH, 1994. - Immunocytochemical localization of mammalian GnRH (gonadotropin-releasing hormone) and chicken GnRH-II in the brain of the European silver eel (*Anguilla anguilla* L.). *J. Chem. Neuroanat.*, 7: 227-241.

MONTERO M. & S. DUFOUR, 1996. - Gonadotropin-releasing hormones (GnRH) in fishes: Evolutionary data on their structure, localization, regulation and function. *Zool. Stud.*, 35: 149-160.

MONTERO M., YON L., ROUSSEAU K., ARIMURA A., FOURNIER A., DUFOUR S. & H. VAUDRY, 1998. - Distribution, characterization and growth hormone releasing activity of pituitary adenylate cyclase-activating polypeptide in the European eel, *Anguilla anguilla*. *Endocrinology*, 139: 4300-4310.

MONTERO M., YON L., KIKUYAMA S., DUFOUR S. & H. VAUDRY, 2000. - Molecular evolution of the growth hormone-releasing hormone/pituitary adenylate cyclase-activating polypeptide gene family. Functional implication in the regulation of growth hormone secretion. *J. Mol. Endocrinol.*, 25: 157-168.

MORIYAMA S., SWANSON P., NISHII M., TAKAHASHI A., KAWAUCHI H., DICKHOFF W. & E. PLISETSKAYA, 1994. - Development of a homologous radioimmunoassay for coho salmon insulin-like growth factor-I. *Gen. Comp. Endocrinol.*, 96: 149-161.

MORIYAMA S., DICKHOFF W.W. & E.M. PLISETSKAYA, 1995. - Isolation and characterization of insulin-like growth factor-I from rainbow trout, *Oncorhynchus mykiss*. *Gen. Comp. Endocrinol.*, 99: 221-229.

MOUNIER F., PELLEGRINI E., KORDON C., EPELBAUM J. & M-T. BLUET-PAJOT, 1997. - Continuous intracerebroventricular administration of a corticotropin releasing hormone antagonist amplifies spontaneous growth hormone pulses in the rat. *J. Endocrinol.*, 152: 431-436.

MURTHY C., ZHENG W., TRUDEAU V., NAHORNIAK C., RIVIER J. & R. PETER, 1994. - *In vivo* actions of a gonadotropin-releasing hormone (GnRH) antagonist on gonadotropin-II and growth hormone secretion in goldfish, *Carassius auratus*. *Gen. Comp. Endocrinol.*, 96: 427-437.

MUSTONEN A.M., NIEMINEN P. & H. HYVARINEN, 2002. - Leptin, ghrelin and energy metabolism of the spawning burbot (*Lota lota* L.). *J. Exp. Zool.*, 293: 119-126.

NAGAMAYSU S., CHAN S.J., FALKNER S. & D.F. STEINER, 1991. - Evolution of the insulin gene superfamily. Sequence of a preproinsulin-like growth factor cDNA from the Atlantic hagfish. *J. Biol. Chem.*, 266: 23397-23402.

NAGY G., VIGH S. & A. ARIMURA, 1993. - PACAP induces prolactin and growth hormone release in lactating rats separated from their pups. *Endocr. J.*, 1: 169-173.

NAMBA H., MORITA S. & S. MELMED, 1989. - Insulin-like growth factor-I action on growth hormone secretion and messenger ribonucleic acid levels: Interaction with somatostatin. *Endocrinology*, 124: 1794-1799.

NEGATU Z. & A.H. MEIER, 1995. - *In vitro* incorporation of 14C glycine into muscle protein of gulf killifish (*Fundulus grandis*) in response to insulin-like growth factor-1. *Gen. Comp. Endocrinol.*, 98: 193-201.

NISHIOKA R., GRAU E. & H. BERN, 1985. - *In vitro* release of growth hormone from the pituitary gland of tilapia, *Oreochromis mossambicus*. *Gen. Comp. Endocrinol.*, 60: 90-94.

O'CONNOR P., REICH B. & M. SHERIDAN, 1993. - Growth hormone stimulates lipid mobilization in rainbow trout, *Oncorhynchus mykiss*. *J. Comp. Physiol.*, 163B: 427-431.

OGI K., KIMURA C., ONDA H., ARIMURA A. & M. FUJINO, 1990. - Molecular cloning and characterization of cDNA for the precursor of rat pituitary adenylate cyclase-activating polypeptide (PACAP). *Biochem. Biophys. Res. Comm.*, 173: 1271-1279.

OHKUBO S., KIMURA C., OGI K., OKAZAKI K., HOSOYA M., ONDA H., MIYATA A., ARIMURA A. & M. FUJINO, 1992. - Primary structure and characterization of the precursor to human pituitary adenylate cyclase-activating polypeptide. *DNA Cell Biol.*, 11: 21-30.

OKAZAKI K., ITOH Y., OGI K., OHKUBO S. & H. ONDA, 1995. - Characterization of murine PACAP mRNA. *Peptides*, 16: 1295-1299.

OLIVEREAU M., OLLEVIER F., VANDESANDE F. & J. OLIVEREAU, 1984. - Somatostatin in the brain and the pituitary of some teleosts. *Cell Tissue Res.*, 238: 289-296.

ONO M., TAKAYAMA Y., RAND-WEAVER M., SAKATA S., YASUNAGA T., NOSO T. & H. KAWAUCHI, 1990. - cDNA cloning of somatolactin, a pituitary protein related to growth hormone and prolactin. *Proc. Natl. Acad. Sci. USA*, 87: 4330-4334.

OYAMA H., BRADSHAW R.A., BATES O.J. & A. PERMUTT, 1980. - Amino acid sequence of catfish pancreatic somatostatin I. *J. Biol. Chem.*, 255: 2251-2254.

PALYHA O.C., FEIGHNER S.D., TAN C.P., McKEE K.K., HRENIUK D.L., GAO Y.D., SCHLEIM K.D., YANG L., MORRIELLO G.J., NARGUND D.L., PATCHETT A.A., HOWARD A.D. & R.G. SMITH, 2000. - Ligand activation domain of human orphan growth hormone (GH) secretagogue receptor (GHS-R) conserved from pufferfish to humans. *Mol. Endocrinol.*, 14: 160-169.

PARHAR I.S. & M. IWATA, 1994. - Gonadotropin releasing hormone (GnRH) neurons project to growth hormone and somatolactin cells in steelhead trout. *Histochemistry*, 102: 195-203.

PARHAR I.S., SATO H. & Y. SAKUMA, 2003. - Ghrelin gene in cichlid fish is modulated by sex and development. *Biochem. Biophys. Res. Comm.*, 305: 169-175.

PARKER D., COE I., DIXON G. & N. SHERWOOD, 1993. - Two salmon neuropeptides encoded by one brain cDNA are structurally related to members of the glucagon superfamily. *Eur. J. Biochem.*, 215: 439-448.

PARKER D., POWER M., SWANSON P., RIVIER J. & N. SHERWOOD, 1997. - Exon skipping in the gene encoding pituitary adenylate cyclase-activating polypeptide in salmon alters the expression of two hormones that stimulate growth hormone release. *Endocrinology*, 138: 414-423.

PARRIZAS M., PLISETSKAYA E.M., PLANAS J. & J. GUTIERREZ, 1995. - Abundant insulin-like growth factor-1 receptor binding in fish skeletal muscle. *Gen. Comp. Endocrinol.*, 98: 16-25.

PATEL Y.C., 1999. - Somatostatin and its receptor family. *Front. Neuroendocrinol.*, 20: 157-198.

PEETERS K., LANGOUCHE L., VANDESANDE F., DARRAS V. & L. BERGHMAN, 1998. - Effects of pituitary adenylate cyclase-activating polypeptide (PACAP) on cAMP formation and growth hormone release from chicken anterior pituitary cells. *Ann. N. Y. Acad. Sci.*, 865: 471-474.

PEREZ F.M., MALAMED S. & C.G. SCANES, 1987. - Growth hormone secretion from chicken adenohypophyseal cells in primary culture: Effects of human pancreatic growth hormone-releasing factor, thyrotropin-releasing hormone, and somatostatin on growth hormone release. *Gen. Comp. Endocrinol.*, 65: 408-412.

PEREZ-SANCHEZ J., WEIL C. & P.-Y. LE BAIL, 1992. - Effects of a human insulin like-growth factor-1 on the release of growth hormone by rainbow trout (*Oncorhynchus mykiss*) pituitary cells. *J. Exp. Zool.*, 262: 287-290.

PERROT V., MOISEEVA E.B., GOZES Y., CHAN S.J., INGLETON P. & B. FUNKENSTEIN, 1999. - Ontogeny of the insulin-like growth factor system (IGF-I, IGF-II, and IGF-IR) in the gilthead seabream (*Sparus aurata*): Expression and cellular localization. *Gen. Comp. Endocrinol.*, 116: 445-460.

PETER R.E., NAHORNIAK C.S., VALE W.W. & J.E. RIVIER, 1984. - Human pancreatic growth hormone-releasing factor (hpGRF) stimulates growth hormone release in goldfish. *J. Exp. Zool.*, 231: 161-163.

PIETERS G., HERMUS A., SMALS A. & P. KLOPPENBORG, 1984. - Paradoxical responsiveness of growth hormone to corticotropin-releasing factor in acromegaly. *J. Clin. Endocrinol. Metab.*, 58: 560-562.

PINILLA L., BARREIRO M.L., TENA-SEMPERE M. & E. AGUILAR, 2003. - Role of ghrelin in the control of growth hormone secretion in prepubertal rats: Interactions with excitatory amino acids. *Neuroendocrinology*, 77: 83-90.

PYKA G., WISWELL R. & R. MARCUS, 1992. - Age-dependent effect of resistance exercise on growth hormone secretion in people. *J. Clin. Endocrinol. Metab.*, 75: 404-407.

RAO S., PRASADA RAO P. & R. PETER, 1996. - Growth hormone-releasing hormone immunoreactivity in the brain, pituitary, and pineal of the goldfish, *Carassius auratus*. *Gen. Comp. Endocrinol.*, 102: 210-220.

REINECKE M. & C. COLLET, 1998. - The phylogeny of the insulin-like growth factors. *Int. Rev. Cytol.*, 183: 1-94.

RESHKIN S.J., GROVER M.L., HOWERTON R.D., GRAU E.G. & G.A. AHEARN, 1989. - Dietary hormonal modification of growth, intestinal ATPase, and glucose transport in tilapia. *Am. J. Physiol,* 256: E610-E618.

RILEY L.G., HIRANO T. & E.G. GRAU, 2002. - Rat ghrelin stimulates growth hormone and prolactin release in tilapia, *Oreochromis mossambicus*. *Zool. Sci.*, 19: 797-800.

RIVIER C. & P.M. PLOTSKY, 1986. - Mediation by corticotrophin-releasing factor (CRF) of adenohypophysical hormone secretion. *Ann. Rev. Physiol.*, 48: 475-494.

ROUSSEAU K., HUANG Y-S., LE BELLE N., VIDAL B., MARCHELIDON J., EPELBAUM J. & S. DUFOUR, 1998. - Long-term inhibitory effects of somatostatin and insulin-like growth factor 1 on growth hormone release by serum-free primary culture of pituitary cells from European eel (*Anguilla anguilla*). *Neuroendocrinology*, 67: 301-309.

ROUSSEAU K., LE BELLE N., MARCHELIDON J. & S. DUFOUR, 1999. - Evidence that corticotropin-releasing hormone acts as a growth hormone-releasing factor in a primitive teleost, the European eel (*Anguilla anguilla*). *J. Neuroendocrinol.*, 11: 385-392.

ROUSSEAU K., LE BELLE N., PICHAVANT K., MARCHELIDON J., CHOW B.K.C., BOEUF G. & S. DUFOUR, 2001. - Pituitary growth hormone secretion in the turbot, a phylogenetically recent teleost, is regulated by a species-specific pattern of neuropeptides. *Neuroendocrinology*, 74: 375-385.

ROUSSEAU K., LE BELLE N., SBAIHI M., MARCHELIDON J., SCHMITZ M. & S. DUFOUR, 2002. - Evidence for a negative feedback in the control of eel growth hormone by thyroid hormones. *J. Endocrinol.*, 175: 605-613.

SAKAMOTO T., MCCORMICK S.D. & T. HIRANO, 1993. - Osmoregulatory actions of growth hormone and its mode of action in salmonids: A review. *Fish Physiol. Biochem.*, 11: 155-164.

SAMUELS H.H. & L.E. SHAPIRO, 1976. - Thyroid hormone stimulates de novo growth hormone synthesis in cultured GH1 cells: Evidence for the accumulation of a rate limiting RNA species in the induction process. *Proc. Natl. Acad. Sci. USA*, 73: 3369-3373.

SCHMID A.C., LUTZ I., KLOAS W. & M. REINECKE, 2003. - Thyroid hormone stimulates hepatic IGF-I mRNA expression in a bony fish, the tilapia *Oreochromis mossambicus*, *in vitro* and *in vivo*. *Gen. Comp. Endocrinol.*, 130: 129-134.

SEOANE L.M., TOVAR S., BALDELLI R., ARVAT E., GHIGO E., CASANUEVA F.F. & C. DIEGUEZ, 2000. - Ghrelin elicits a marked stimulatory effect on GH secretion in freely moving rats. *Eur. J. Endocrinol.*, 143: R7-R9.

SHAMBLOTT M.J., CHENG C.M., BOLT D. & T.T. CHEN, 1995. - Appearance of insulin-like growth factor mRNA in the liver and pyloric caeca of a teleost in response to exogenous growth hormone. *Proc. Natl. Acad. Sci. USA*, 92: 6943-6946.

SHEPHERD B.S., ECKERT S.M., PARHAR I.S., VIJAYAN M.M., WAKABAYASHI I., HIRANO T., GRAU E.G. & T.T. CHEN, 2000. - The hexapeptide KP-102 (D-ala-D-beta-Nal-ala-trp-D-phe-lys-NH(2)) stimulates growth hormone release in cichlid fish (*Oreochromis mossambicus*). *J. Endocrinol.*, 167: R7-10.

SHERIDAN M., 1994. - Regulation of lipid metabolism in poikilothermic vertebrates. *Comp. Biochem. Physiol.*, 107B: 495-508.

SILVERMAN B., KAPLAN S., GRUMBACH M. & W. MILLER, 1988. - Hormonal regulation of growth hormone secretion and messenger ribonucleic acid accumulation in cultured bovine pituitary cells. *Endocrinology*, 122: 1236-1241.

SMITH R.G., VAN DER PLOEG L.H., HOWARD A.D., FEIGHNER S.D., CHENG K., HICKEY G.J., WYVRATT M.J. Jr, FISHER M.H., NARGUND R.P. & A.A. PATCHETT, 1997. - Peptidomimetic regulation of growth hormone secretion. *Endocr. Rev.*, 18: 621-645.

SMITH R.G., FEIGHNER S., PRENDERGAST K., GUAN X. & A. HOWARD, 1999. - A new orphan receptor involved in pulsatile growth hormone release. *Trends Endocrinol. Metab.*, 10: 128-135.

SUN L.-Z. & A. FARMANFARMAIAN, 1992. - Biphasic action of growth hormone on intestinal amino acid absorption in striped bass hybrids. *Comp. Biochem. Physiol.*, 103A: 381-390.

SUZUKI R., KISHIDA M. & T. HIRANO, 1990. - Growth hormone secretion during longterm incubation of the pituitary of the Japanese eel, *Anguilla japonica*. *Fish Physiol. Biochem.*, 8: 159-165.

TAKAYA K., ARIYASU H., KANAMOTO N., IWAKURA H., YOSHIMOTO A., HARADA M., MORI K., KOMATSU Y., USUI T., SHIMATSU A., OGAWA Y., HOSODA K., AKAMIZU T., KOJIMA M., KANGAWA K. & K. NAKAO, 2000. - Ghrelin strongly stimulates growth hormone release in humans. *J. Clin. Endocrinol. Metab.*, 85: 4908-4911.

TANIYAMA S., KITAHASHI T., ANDO H., KAERIYAMA M., ZOHAR Y., UEDA H. & A. URANO, 2000. - Effects of gonadotropin-releasing hormone analog on expression of genes encoding the growth hormone/prolactin/somatolactin family and a pituitary-specific transcription factor in the pituitaries of prespawning sockeye salmon. *Gen. Comp. Endocrinol.*, 118: 418-424.

TOLLE V., ZIZZARI P., TOMASETTO C., RIO M-C., EPELBAUM J. & M-T. BLUET-PAJOT, 2001. - *In vivo* and *in vitro* effects of ghrelin/motilin-related peptide on growth hormone secretion in the rat. *Neuroendocrinology*, 73: 54-61.

TRUDEAU V., SOMOZA G., NAHORNIAK C. & R. PETER, 1992. - Interactions of estradiol with gonadotropin-releasing hormone and thyrotropin-releasing hormone in the control of growth hormone secretion in the goldfish. *Neuroendocrinology*, 56: 483-490.

TSE M.C., VONG Q.P., CHENG C.H. & K.M. CHAN, 2002. - PCR-cloning and gene expression studies in common carp (*Cyprinus carpio*) insulin-like growth factor-II. *Biochim. Biophys. Acta*, 1575: 63-74.

UNNIAPPAN S., LIN X., CERVINI L., RIVIER J., KAIYA H., KANGAWA K. & R.E. PETER, 2002. - Goldfish ghrelin: Molecular characterization of the complementary deoxyribonucleic acid, partial gene structure and evidence for its stimulatory role in food intake. *Endocrinology*, 143: 4143-4146.

VALCAVI R., ZINI M. & I. PORTIOLI, 1992. - Thyroid hormones and growth hormone secretion. *J. Endocrinol. Invest.*, 15: 313-330.

VALE W., VAUGHAN J., YAMAMOTO G., SPIESS J. & J. RIVIER, 1983. - Effects of synthetic human pancreatic (tumor) GH releasing factor and somatostatin, triiodothyronine and dexamethasone on GH secretion *in vitro*. *Endocrinology*, 112: 1553-1555.

VAUDRY D., GONZALEZ B.J., BASILLE M., YON L., FOURNIER A. & H. VAUDRY, 2000. - Pituitary adenylate cyclase-activating polypeptide and its receptors: From structure to functions. *Pharmacol. Rev.*, 52: 269-324.

VAUGHAN J., RIVIER J., SPIESS J., PENG C., CHANG J., PETER R. & W. VALE, 1992. - Isolation and characterization of hypothalamic growth hormone-releasing factor from common carp, *Cyprinus carpio*. *Neuroendocrinology*, 56: 539-549.

VIDAL B., LE BELLE N., KAPSIMALI M., ROUSSEAU K., VERNIER P. & S. DUFOUR, 2000. - Dopamine and its D1 receptor do not control growth hormone (GH) release in the eel, *Anguilla anguilla*. *In*: 20th Conference European Comparative Endocrinology, Faro, Portugal, p. 115 (Abstract).

VON HORN H., EKSTROM C., ELLIS E., OLIVECRONA H., EINARSSON C., TALLY M. & T.J. EKSTROM, 2002. - GH is a regulator of IGF2 promoter-specific transcription in human liver. *J. Endocrinol.*, 172: 457-465.

WEBER M.M., MELMED S., ROSENBLOOM J., YAMASAKI H. & D. PRAGER, 1992. - Rat somatotroph insulin-like growth factor-II (IGF-II) signaling: Role of the IGF-I receptor. *Endocrinology*, 131: 2147-2153.

WEIL C., CARRE F., BLAISE O., BRETON B. & P.-Y. LE BAIL, 1999. - Differential effect of insulin-like growth factor I on *in vitro* gonadotropin (I and II) and growth hormone secretions in rainbow trout (*Oncorhynchus mykiss*) at different stages of the reproductive cycle. *Endocrinology*, 140: 2054-2062.

WONG A.O., CHANG J.P. & R.E. PETER, 1992. - Dopamine stimulates growth hormone release from the pituitary of goldfish, *Carassius auratus*, through the dopamine D1 receptors. *Endocrinology*, 130: 1201-1210.

WONG A., CHANG J. & R. PETER, 1993a. - Interactions of somatostatin, gonadotropin-releasing hormone, and the gonads on dopamine-stimulated growth hormone release in goldfish. *Gen. Comp. Endocrinol.*, 92: 366-378.

WONG A.O., CHANG J.P. & R.E. PETER, 1993b. - *in vitro* and *in vivo* evidence that dopamine exerts growth hormone-releasing activity in goldfish. *Am. J. Physiol.*, 264: E925-932.

WONG A.O.L., LEUNG M.Y., SHEA W.L.C., TSE L.Y., CHANG J.P. & B.K.C. CHOW, 1998a. - Hypophysiotropic action of pituitary adenylate cyclase-activating polypeptide (PACAP) in the goldfish: Immunohistochemical demonstration of PACAP in the pituitary, PACAP stimulation of growth hormone release from pituitary cells, and molecular cloning of pituitary type I PACAP receptor. *Endocrinology*, 139: 3465-3479.

WONG A.O.L., NG S., LEE E.K.Y., LEUNG R.C.Y. & W.K.K. HO, 1998b. - Somatostatin inhibits (D-Arg6, Pro9-NEt) salmon gonadotropin-releasing hormone- and dopamine D1-stimulated growth hormone release from perifused pituitary cells of Chinese Grass carp, *Ctenopharyngodon idellus*. *Gen. Comp. Endocrinol.*, 110: 29-45.

YADA T. & T. HIRANO, 1992. - Inhibition of growth hormone synthesis by somatostatin in cultured pituitary of rainbow trout. *J. Comp. Physiol.*, 162B: 575-580.

YADA T., URANO A. & T. HIRANO, 1991. - Growth hormone and prolactin gene expression and release in the pituitary of rainbow trout in serum-free culture. *Endocrinology*, 129: 1183-1192.

YAMASHITA S. & S. MELMED, 1986. - Insulin-like growth factor I action on rat anterior pituitary cells: Suppression of growth hormone secretion and messenger ribonucleic acid levels. *Endocrinology*, 118: 176-182.

YAMAZAKI M., NAKAMURA K., KOBAYASHI H., MATSUBARA M., KANGAWA K. & T. SAKAI, 2002. - Regulational effect of ghrelin on growth hormone secretion from perifused rat anterior pituitary cells. *J. Neuroendocrinol.*, 14: 156-162.

YAO K., NIU P-D., LE GAC F. & P-Y. LE BAIL, 1991. - Presence of specific growth hormone binding sites in rainbow trout (*Oncorhynchus mykiss*) tissues: Characterization of hepatic receptor. *Gen. Comp. Endocrinol.*, 81: 72-82.

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